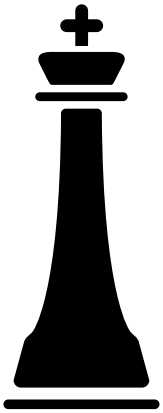
CHESS ON AN INFINITE PLANE

A-LEVEL COMPUTER SCIENCE COURSEWORK
H446



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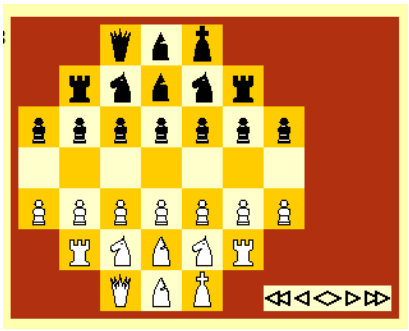
Problem Identification

Chess has been around for hundreds of years. The idea of a machine that could play chess has been around since the 18th century, and it is therefore unsurprising that computer scientists have been interested in using a computer to play chess ever since the computer was invented. A very important paper on the matter, "Programming a Computer for Playing Chess" was published in 1950 by Claude Shannon, which kickstarted the process of modern computers being programmed to play chess.

There are countless variations of chess, many of which would not be possible to play (conveniently or at all) without the use of computers. Many of these variants are easily able to be found and played online, with some simply changing the layout of pieces, others having completely different pieces or even board shapes.



"Chess with 37 squares"

The problem is that the sites I found to play these variations are all rather dated, and the games are Java applets. Google Chrome, the most widely used browser, doesn't even support this anymore, so I had to open internet explorer, install Java, then I had to add this site to a security exception list just to run a chess variant which is low quality and unentertaining. My client, Adnan Ahmad, wants to play a chess variant, but doesn't want to have to go through this process for a less than satisfactory experience.

One of the sites I found listed over one hundred chess variants available to play. Some of these are simpler than others from a programming perspective. However, the one variant I have not seen online is "chess on an infinite plane", also known as infinite chess, in which the chess board is unbounded. This is the variant I will choose to tackle; an infinite board will create more of a challenge from a development point of view, and will be very different to play compared to regular chess.

Problem Computability

There are multiple points to consider when thinking about the computability of the solution to the client's problem:

- Feasibility
  - Chess on an infinite plane would be very difficult to create using a physical board and pieces.
  - There is the logistical issue of not actually being able to have a board of infinite size.
  - Either a board will have to be sufficiently large that the difference is not relevant, or some method must be used to keep track of where pieces that have moved off the board are.
- Convenience
  - Unorthodox pieces will be difficult to obtain physically, which may cause the game to be unplayable.
  - Having a very large board or keeping track of where every piece is simply not convenient.
  - With so many pieces and such a large board, it will be difficult to calculate where pieces can move and what effects this might have (i.e. check).
- Usability
  - Allowing the program to calculate where pieces can move to and if any given move is legal takes a lot of mental pressure off players.
  - Use of an AI will allow just one person to play this game, which is not possible with a physical version. This will allow someone who wants to play the game to do so even if they cannot find another person.
- Expense
  - Both financial and "spacial" costs are minimised with a digital approach.
  - A physical solution requires a board, a large number of pieces, and any additional equipment needed to track everything.
  - A digital solution only takes up space in secondary storage, and costs very little.

Overall, it seems more sensible to approach this digitally, as the very nature of chess on an infinite plane makes it difficult to reproduce in the real world.

Stakeholder Outline

The stakeholders of this solution are people who are interested in chess, but want to play it in a new, reinvented way easily, such as my client Adnan. However, this could also be suited for chess beginners as a different but fun game. As a result, variable difficulty will probably be something the stakeholders would be interested in, so that anyone of any skill level is able to play.

The solution should solve the problem of not being able to conveniently play a chess variant, as this will be a standalone program, so there will be no need to try and find it online, and certainly no need to play in physical space. The offline nature of this solution can make it ideal for killing boredom in situations where there is no access to internet.

Stakeholder Preferences

I need to collect data on the way the stakeholders think this solution should manifest. My main concern will be the preferences of my client, Adnan Ahmad, since this is catered to the problem he encountered. There are various ways I can collect the data I need, each with advantages and disadvantages:

- Surveys
  - These will allow me to collect information from a lot of people in a short amount of time, since I only have to write the survey once.
  - These do not allow me to get detailed answers, since most answers will be yes/no or a number.
  - This makes surveys suitable for deciding what from a predetermined list of features should be present in the program, and maybe even finding out how important features are relative to each other.
- Observations
  - This involves me observing a stakeholder playing either regular chess or a chess variant.
  - This will allow me to see which features are used more or less between versions of the game.
  - This is useful because there may be something that cannot be asked in the survey, but observing someone will give me information about the importance of it.
  - It also shows how stakeholders use all the features of a game together while playing, rather than using features individually.
  - However, this method is time-consuming, so it cannot be for as many stakeholders as a survey.
  - Observations will be a good way to decide on user experience features, such as visuals, animations and helpers.

- Interviews
  - These allow me to talk one-to-one with a stakeholder.
  - This allows me to collect a lot of information; I can ask them more open questions and get a detailed answer about their preferences.
  - However, it is very time consuming. I will only conduct an interview with my client because he is the person I am catering this to.
- Existing Solutions
  - This involves me investigating existing products of a similar description.
  - This will allow me to investigate well-established features of the variants of chess.
  - I can also look at online reviews of variants to gather additional information on what to include and what not to include.
  - This is quite a slow way to collect information, and doesn't give me any information on stakeholder experience.

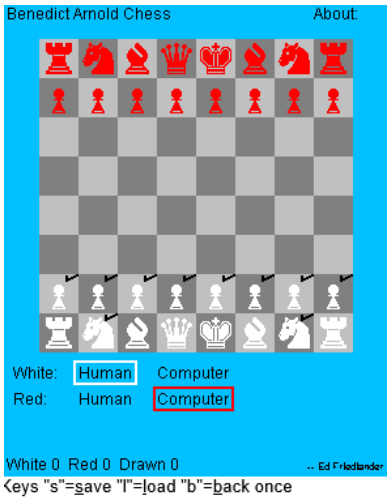
After weighing up these options, I have decided that my main methods will be surveys and interviews. It is difficult to look at existing solutions since there aren't any for my specific idea, and similar solutions are rather limited technically and no reviews exist for them, so I will only cover them briefly. Observation has similar drawbacks, but I can at least look at how people actually play the game, and see if there's any missing features that impact their experience.

Surveys will allow me to ask many people opinions on basic questions, such as "Should feature X be included?", while a client interview will allow me to ask more in-depth questions. A survey should be completed before doing an interview so that me and my client are aware of the basic features that will be present, which will then allow my questioning to be much more specific.

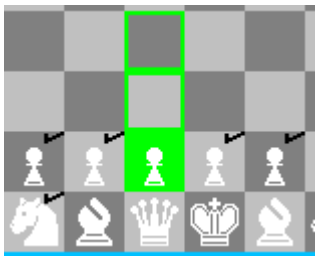
Existing Solutions

I will find and analyse some existing chess variants to see what features they have that I should also add, and what they're missing.

The site I found for chess variants was Pathguy[1], which contains over a hundred chess variants able to be played. The first thing I noticed when attempting to play one was that Google Chrome, my usual browser, does not support Java anymore. I then tried Internet Explorer, which does support Java, but the app would not run because it did not have a sufficient security rating. To fix this, I had to open the Configure Java panel, add this site to the security exception list, and then run the game. This is overall a very inconvenient process just to play chess, so I can already make an improvement over this.



Moving on, I picked a variant at random ("Benedict Arnold Chess") to look at how the game plays. The graphics are very simplistic, which was to be expected as this site is old (2005). Despite this, there are a few notable features of this game. The opponent can be either human or AI, which makes this suitable for people who don't have another person to play with. The player's possible moves are calculated every turn, and clicking on a piece shows them. This may be desirable for some players as it means they can focus more on which move is the best move rather than what moves actually exist. Pieces that can move have a ✓ added to the top right of the square, while pieces that have no moves do not. This is also useful for the reason mentioned previously.



A perhaps even more interesting feature is the rewind, save and load feature, seen at the bottom in the first image. 'back once' rewinds the board by one move, which means it keeps track of the last turn, but it does not go further than that. 'save' will save the current board state, and 'load' will load the last saved state. These are noteworthy because they can be useful for less experienced players, allowing them to try a move and see the outcome without fully committing to it.

These features represent things that cannot be done with a physical solution for any chess game, so adding them as part of my solution, maybe even as toggleable options, seems like the most sensible thing to do, as they will enhance the user experience.

I notice that there are some features missing too. A lack of a variable AI difficulty makes this game more difficult than intended for beginners and trivial for good players, which removes these two groups of people from finding the game enjoyable. For this reason, I think it will be important that my solution has the ability to change difficulty. Furthermore, there are no animations at all for any piece movement, and as

mentioned earlier, the graphics are very simple. This may be undesirable for my stakeholders since modern games have much better graphics and animations compared to this. I will discuss this in the client interview to see what Adnan thinks.

Survey Design

I will try to avoid written answers in the survey when possible, since people will want to complete it quickly and multiple-choice answers will be much faster.

1 *Which Operating System do you use?*

This question is important because it is not easy to make an application that will work out of the box on all operating systems. However, it is expected that most responses will be a Windows variant, since this is the most commonly used OS.

2 *How often do you play chess, online or offline (1 being seldom, 5 being very frequently)?*

This question gives me a basic insight into how much the person plays chess in any form. This will allow me to judge how important these preferences are compared to others.

3 *Which opponent(s) would you want in the game?*

This question will have options “AI”, “Human” or “Both”. This will allow me to see which opponent people prefer playing against, and if they would like the option for both. This is important to know because an AI will add additional time to development.

4 *How important are the following features to you (1 being not important at all and 5 being very important)?*

Variable AI Difficulty

Move History

Coordinate Display

Main Menu

Custom Colours

Custom Start Configuration

Move Rewinding

These are various features that could be in the game. This question will allow me to gain insight into which of these are more important in the view of my stakeholders. Knowing this allows me to better create interview questions for my client, and I can then see where he agrees and disagrees.

5 *What are the specifications of the computer system you use?*

CPU Clock Speed: ___ GHz *CPU Cores: ____ Cores*

GPU Model: _____

RAM: ___ GB *Secondary Storage Capacity: _____ GB*

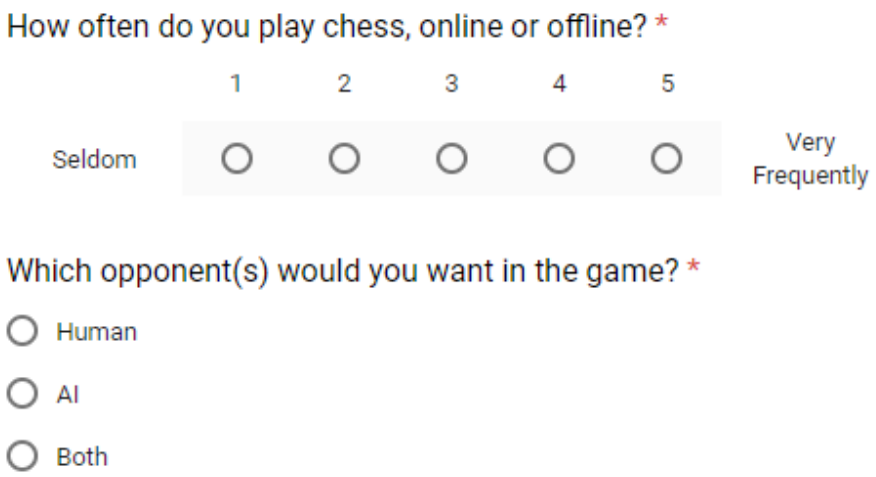
Monitor Resolution: _____

It is unlikely that any of the stakeholders will be unable to run the game on their current system, as it has very low graphical intensity. However, resolution will be an important thing to consider as many people use laptops. While newer laptops are 1920x1080, some people using older laptops may have 720p monitors, so it could be necessary to accommodate for this.

I will use Google Forms to collect this data, as this is more convenient for both me and the people filling it in; I don't have to hand out physical surveys and collect them again, the results are automatically collated for me, and it's easy for others to just click the link and fill it in.

I will provide a link to everyone in my Computing class, which should provide me with a reasonable sized set of data to work with.

Below is the finished form:



How important are the following features to you (1 being not important at all and 5 being very important)? *

	1	2	3	4	5
Variable AI Difficulty	☐	☐	☐	☐	☐
Move History	☐	☐	☐	☐	☐
Coordinate Display	☐	☐	☐	☐	☐
Main Menu	☐	☐	☐	☐	☐
Custom Colours	☐	☐	☐	☐	☐
Custom Start Configuration	☐	☐	☐	☐	☐
Move Rewinding	☐	☐	☐	☐	☐

Which Operating System do you use? *

- ○ Windows 7 and later
- ○ Windows Vista and earlier
- ○ Mac OS X
- ○ Linux
- ○ Other: _____

What is the clock speed of your CPU? *

Your answer

What is the capacity of your hard drive? *

Your answer

What is the resolution of your monitor? *

- ○ 3840x2160
- ○ 1920x1080
- ○ 1280x1024
- ○ 1600x900
- ○ 1280x720
- ○ Other: _____

How many cores does your CPU have? *

- ○ 1
- ○ 2
- ○ 3
- ○ 4
- ○ 6
- ○ 8
- ○ 10 or more
- ○ Other: _____

What is your GPU model?

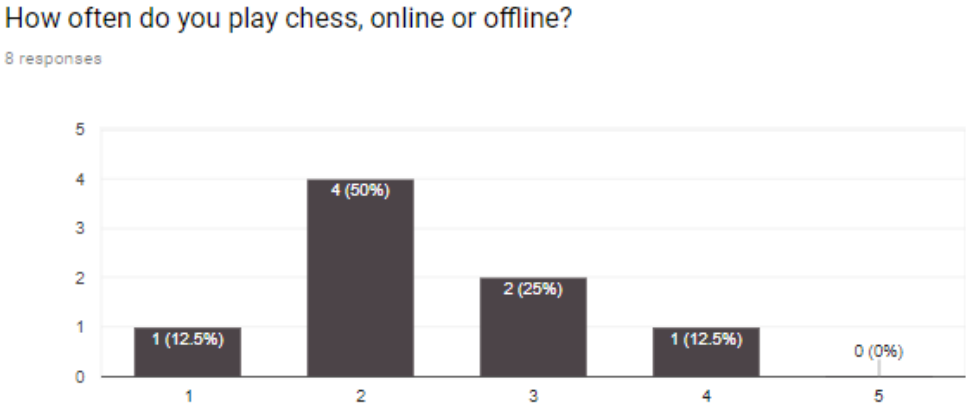
Your answer

How much RAM do you have? *

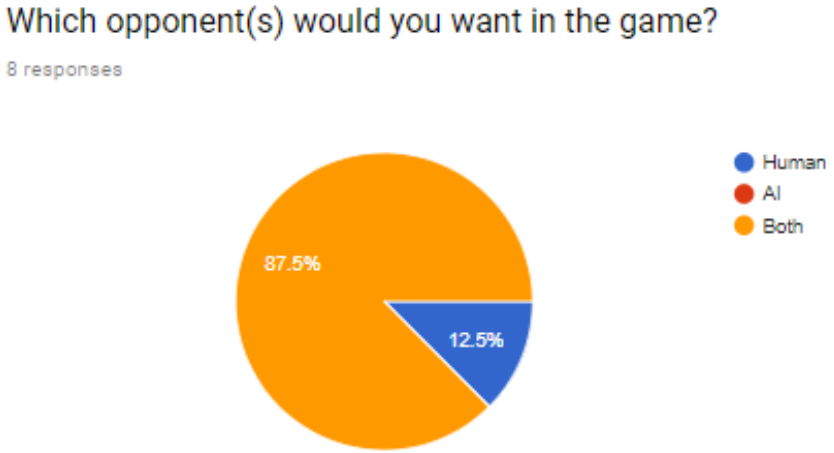
- ○ 1GB or less
- ○ 2GB
- ○ 4GB
- ○ 6GB
- ○ 8GB
- ○ 12GB or more

Survey Result Analysis

- Question 1
  - Many of the people that responded do not play chess very frequently. However, that doesn't completely invalidate their opinions on what features should be in my solution, since it is likely that most of them do understand chess at a basic level at least, and have played some online version of chess at some point.



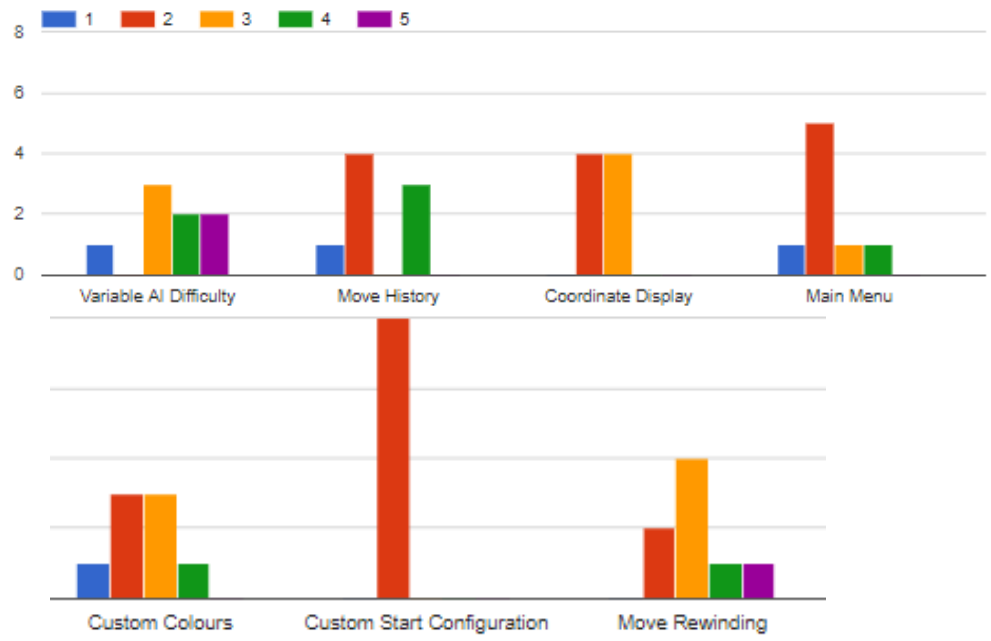
- Question 2
  - An overwhelming majority of responses asked for both human and AI opponents in the game. This is significant because creating an AI will add to the total development time, so I must make sure I have enough time to get this feature in. However, adding support for both will increase the usefulness of my solution, since it is now both a 1-player and a 2-player game.



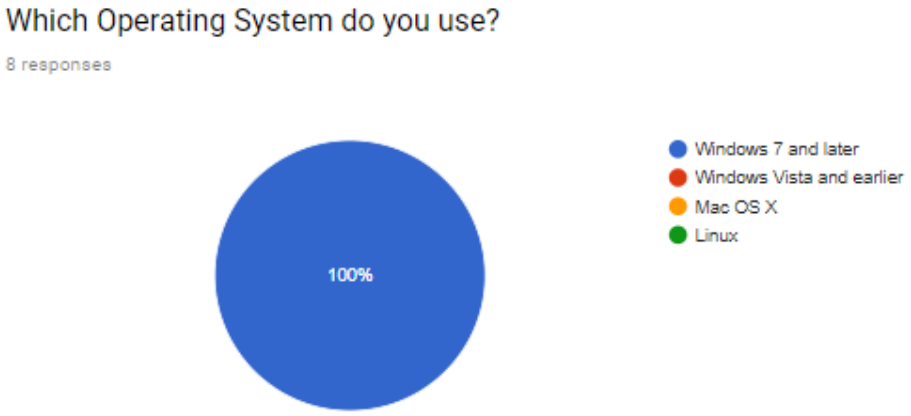
- Question 3
  - Variable AI Difficulty seems to be considered fairly important, with an average score of 3.5. This makes sense, as a variable AI difficulty will allow the game to be played by people of all skill levels. As a result, this will be a feature I will include in the solution.

- 5 people gave Move History a 1 or 2, while 3 gave it a 4. This shows a divide between people wanting this feature and people that don't. The average score for this was 2.6, however I think it would be a useful feature, so I will need to speak to my client and see if it's something he would be interested in.
- Coordinate Display scored an average of 2.5, and it is a minor feature so it is unlikely I will put coordinates on individual squares or have a display for the current coordinates. I also haven't seen this on any existing solutions, so I will probably just go with the more common feature of displaying row and column letters/numbers around the board.
- Most people scored Main Menu a 2. I do not think a main menu is too important for a game like this; I envisage it being similar to the games that come with Windows 7, such as Solitaire or Minesweeper, in the sense that there is no main menu, and a toolbar at the top of the screen is used instead.
- Custom Colours and Start Configurations scored fairly low (2.5 and 2, respectively). This is expected because they are very minor features and don't really impact the game a huge amount. Since these are not important according to the survey results, I will not be adding them to the final solution.
- Move Rewinding scored 3.1, so it is seen as fairly important. I think it is an important feature for the same reason as Variable AI Difficulty is. I will discuss this feature with Adnan to see if it's something he thinks is important for the game.

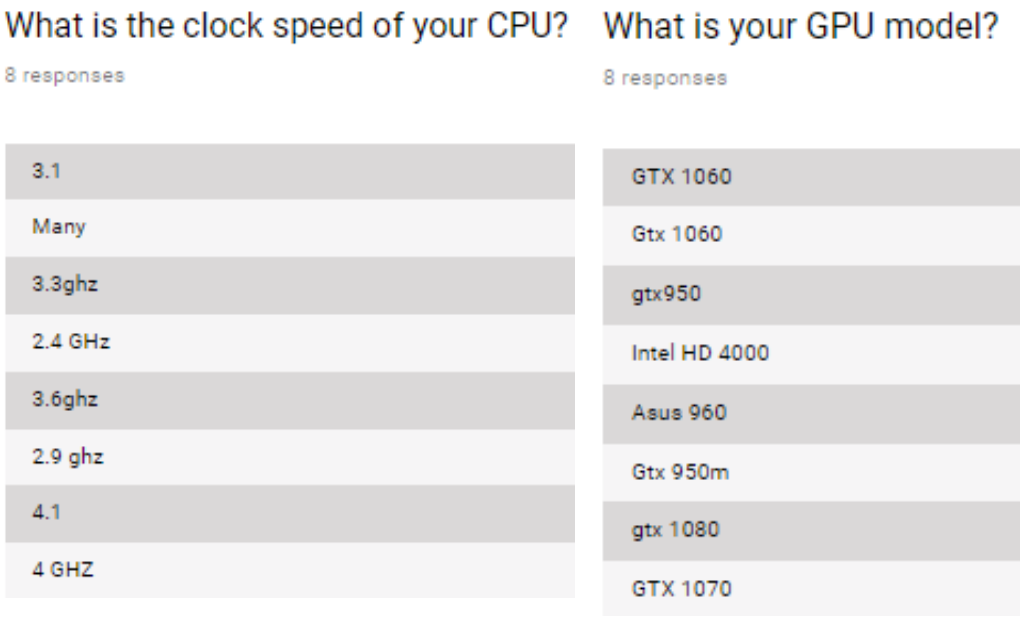
How important are the following features to you (1 being not important at all and 5 being very important)?

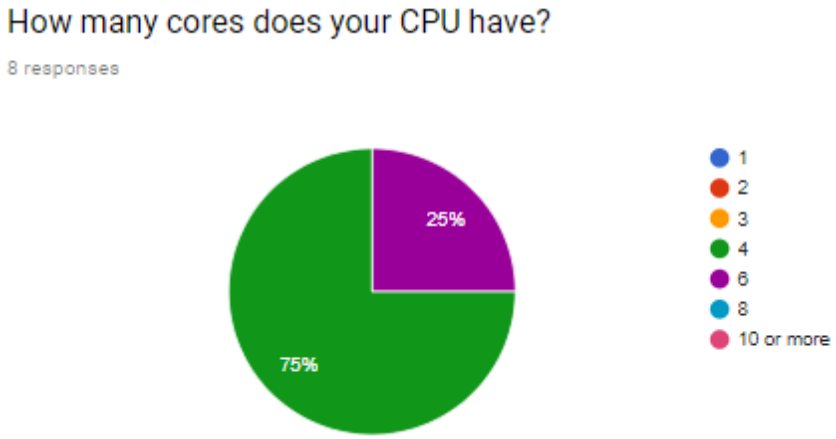


- Question 4
  - Every person who responded gave Windows 7 or later as their OS. Assuming my client also uses Windows, I will not make any attempt to support other operating systems, since it is a fair assumption that a vast majority of people that would use this software will be on a recent version of Windows. This means I am free to use my language of choice, C#, which is part of .NET.

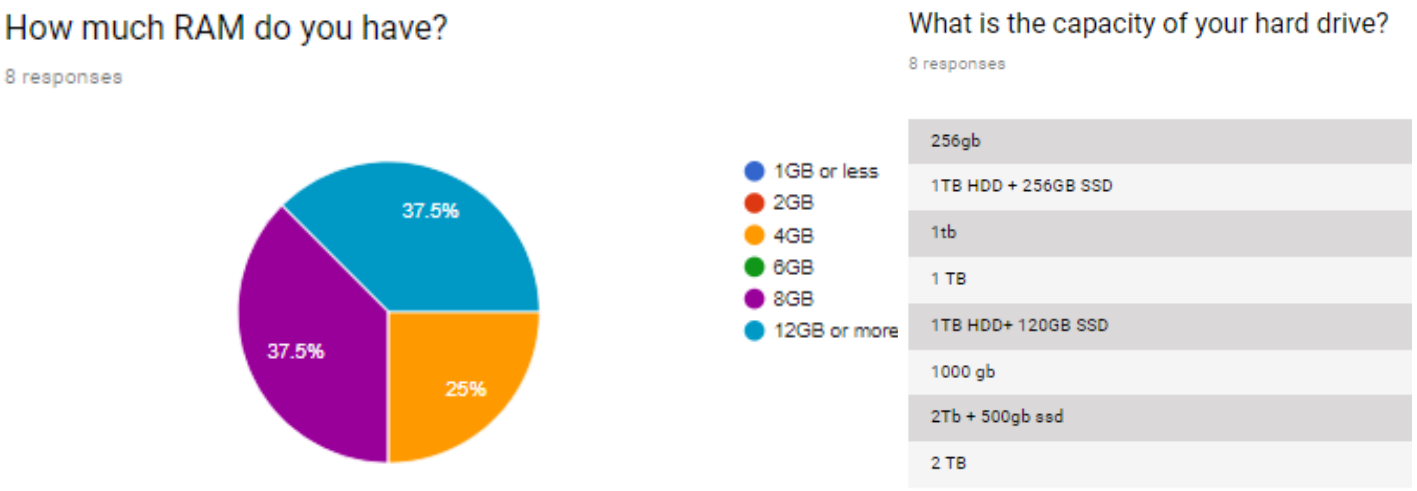


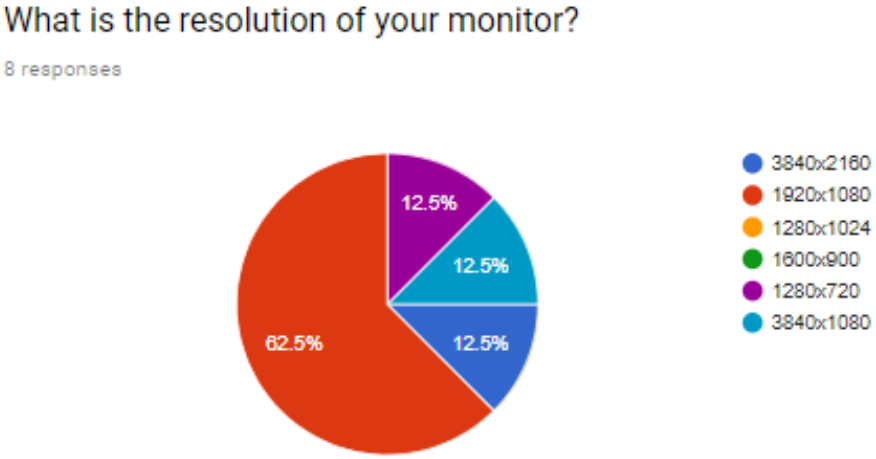
- Questions 5, 6 and 7
  - The people who responded to the survey have generally high quality CPUs and GPUs. The average clock speed is 3.3GHz, and 100% are 4 or more cores. My solution is very light on graphics and processing anyway so there should be no problems with performance for any modern computer system, and certainly not on any of the systems owned by the people who responded. GPU is not really a concern since the game will use the CPU because of the very low intensity graphics.





- Questions 8 and 9
  - Similarly, most responses have ample amounts of RAM and secondary storage space. My game will use very little of both of these, so there will certainly be no performance issues.





- Question 10
  - 63% of responses had a 1920x1080 monitor. However, there were some responses for other sizes too, notably 1280x720. I will ask my client about the resolution of his own monitor. 1080p is the most common resolution so I must make sure the game looks correct on this resolution. 720p is used on a lot of somewhat old laptops, and I am also developing the game on a 720p monitor. This means I will need to have the game able to scale with both sizes, and test 1080p on another device. I could also add support for other resolutions, but these two are the priority.

Overall, the most important features according to this survey are those which accommodate for players of different skill levels. People were not so interested in minor customisation options. There are no problems with computer specifications in relation to possible performance issues, since my game will be lightweight and responses to the survey have good computer systems. I will discuss with my client monitor resolution to see if I need to make support for anything other than 1080p and 720p.

Client Interview

After the surveys and existing solution research, there are still a few questions I need to clear up. This will be done with an interview with my client Adnan, as he is the person I am catering this solution to.

The things I need to decide on are those where the result from the survey is not clear and it is not obvious what my client would want without asking. These things are the main menu, colour customisation, and variable AI difficulty. I also need to ensure that my hardware requirements are suitable for my client.

Me: Ok, so there's a few things I need to clear up before I can write the specification. First, you're using Windows 10, right?

Adnan: Yeah.

M: Ok good, and what's the resolution if your monitor?

A: It's 1080p.

M: Right, that's the technical stuff out the way. Now for actual features; what do you think about a variable AI difficulty?

A: I think it's a great idea, because I have found that many existing variants of chess fail to challenge me.

M: That's what I expected, I agree that it will be a useful feature. Is move rewinding a feature you would be interested in also?

A I think it's a good idea for other players, however for me, as I am looking for a chess variant with greater difficulty, I don't feel it's necessary.

M: A lot of people in the survey said they weren't too interested in a main menu. I was thinking of making it like those games that come with Windows, like solitaire and stuff, where there's no main menu and everything is done with a toolbar at the top. What do you think about that?

A: I agree, I feel it makes navigation much quicker and efficient, and means when I launch the game I can get stuck in to the game.

M: Ok, how about more superficial features like colours and themes. Do you want those in the game, or are they unnecessary?

A: I don't think this is necessary, and may be in some cases distracting to the players.

M: Oh, and a move history, are you interested in seeing the previous moves?

A: Definitely, as someone who often loses track of moves, this would really be useful to me, and I think to a lot of other players.

M: Ok that has cleared up those last details for me. Thanks.

A: No problem.

Interview Analysis

From the interview, we can decide on a number of features:

- The solution will be aimed solely at Windows Vista and newer version of Windows. None of the responses to the survey had older versions, and my client is on Windows 10. Visual Studio 2017 will natively support Windows Vista and after, and will support XP to an extent. To ensure that everything will always work with no compatibility issues, I will state the requirement as Windows 7 and later.
- There will not be a main menu. It scored low on the survey, and my client said he was not interested in this feature, preferring a toolbar for more efficient navigation. It is also faster for me to implement a toolbar compared to a main menu, so that is what I will do.
- There will be no customisation for colours or board configurations. These are minor features, and my client is not interested in them because they will act as distractions.

Development

I will be developing this game using Visual Studio 2017. This is an IDE that supports many different .NET languages, such as C#, C++, Visual Basic and F#. I chose this software because it has many useful features for developers, including detailed compiler error reports, CPU and RAM usage, auto-completion, and real-time syntax error checking.

My language of choice will be C#. In Visual Studio, I can create Windows Forms with C#, which means I do not have to spend time developing my own GUI components; they are already supplied for me to use. C# is preferable for me over the other available languages which support Windows Forms because I have a reasonable amount of prior experience with the language. This means I do not need to worry about mistakes involving the use of the language (i.e. syntax errors) as much as about logical errors.

Essential Features

Compiling the results from the existing solutions, surveys and client interview, I have decided on a list of essential features:

- Standalone Offline Application
  - My client's problem is that it is inconvenient to play an online chess variant because of all the steps required. I will resolve this by making my solution an offline executable in C#, so any modern Windows machine will be able to run it out of the box with no issues. This addresses the main issue of my client.
- Response to Resolution
  - While a large proportion of the people who completed the survey had 1080p monitors, there are some others with different resolutions such as 720p too (I am actually developing this on a laptop with a 720p

monitor). For this reason, I think it is important to account for at least these two resolutions, whether it is automatic or manual, so that the game will look correct regardless.

- Human and AI Opponent
  - There was a lot of request from the surveys and also from my client to have both AI and human opponents available. This is an important feature because it will allow someone to play the game even if they don't have another person to play with. This was also a feature in the chess variants researched in existing solutions.
- Variable AI Difficulty
  - This is seen as an important feature to both the people that filled out the survey and to my client. This gives the game a much wider audience, since inexperienced players can play without the AI being too difficult, and experienced players can challenge themselves against a difficult AI. My client has also said that this feature will allow him to continue playing the game as he improves.
- Move Rewinding
  - Similar to the reasons for variable difficulty; move rewinding gives less experienced players a chance to be able to play by not punishing them so hard for mistakes. More experienced players can simply not use this option to give themselves extra challenge.
- Move History
  - This will allow players to keep track of moves that have occurred. Due to the nature of the game, not all pieces will be visible to the player at once, so being able to find out where all pieces are will be very helpful.

Solution Limitations

There are some features that will not be included because they are either not wanted or would detract too much from the development of more important features:

- No Online Capability
  - Online play would add another level of complexity to the game, which I do not have time to develop. This solution is not aimed at those who wish to play online; only for either one or two players.
- No Main Menu
  - A main menu was not seen as important by either my client or the survey responses, so it will not be implemented. A toolbar will be used instead for navigation.
- No Colour Customisation
  - Colour customisation is a minor feature which does not really add or detract anything in terms of actual gameplay. My client said in the interview that this would only serve as a distraction, so I will not develop this feature.

- Windows Vista and Later
  - Visual Studio 2017 will natively support operating systems from Vista onwards. This means I will not be supporting any previous ones, namely XP. This is unlikely to be a problem because few people are using Windows XP (none from the survey responses).

Software Requirements

My success criteria are represented by the software requirements.

- Technical
  1. Generates squares on the fly*.
  2. Game will be saved on exit*.
  3. Can resize to fit different resolutions.
- Gameplay
  4. Has move rewinding.
  5. Has human or AI opponent.
  6. Has variable AI difficulty.
- UI
  7. Has a toolbar for navigation.
  8. Has move history on screen.
  9. Has on-screen buttons to scroll the board*.
  10. Shows the user where they can move when they click on a piece.
  11. Shows the user which pieces have been taken*.
- User Experience
  12. Has keyboard keys to scroll the board*.
  13. The undo button can be disabled.
  14. Tells user if an attempted move is invalid.

Criteria marked with * have not been justified previously and therefore will be below:

- The board will begin at the size that can be seen on screen. As the user scrolls using the buttons, the board will automatically expand. This cuts down on loading time since the program does not need to load a large number of squares at start-up, and also makes the program more memory efficient since only squares that are actually needed will be generated and saved.
- When the game is exited, the current game state will be saved. Some games could go on for some time depending on how the user plays, so being able to pick up a game part way through at a later time is better for user experience.
- Buttons will be used to scroll the board. I decided to use buttons instead of a scroll bar because I feel a scrollbar will not provide the level of precision a user would want in this game. Also there is the issue of the scroll bar becoming too small to use when the board has large dimensions. Keyboard buttons are present to allow for faster and easier scrolling if desired.
- Similar to the move history, a display of which pieces have been taken will be useful for the user to keep track of what has happened. Since infinite chess has

a lot of extra pieces, it can be difficult to notice if one is missing. This feature will take the responsibility of remembering which pieces are gone off the user.

Hardware Requirements

- Resolution
  - 1920x1080 or 1366x768
  - 1080p is the most common monitor resolution, so it is vital that the game is compatible with this resolution. Many somewhat old laptops have a resolution of 720p (and so does the device I am developing this on), so I will also be implementing support for this.
- CPU
  - 1GHz, Dual Core or better
  - The game will not be very intensive at all from a computational standpoint; it is a 2D game with low resolution graphics and relatively simple algorithms. As a result, not a lot of CPU power is required.
- RAM
  - 1GB
  - The amount of RAM the program requires will be very small. This requirement represents the RAM you would need to run an operating system that is compatible with the game.
- Storage Space
  - 500MB
  - This is not a complex game overall; the only things that need to be stored aside from the program itself are images used in the game, saved games, and any user settings. Therefore a very little amount of free hard drive space is needed.
- GPU
  - N/A
  - Since the game uses simple 2D graphics in a Windows Form, the CPU will handle the graphics. Any CPU that is powerful enough to run the program will have an integrated GPU powerful enough to handle the graphics.

Section 2: Design

Decomposition

To decompose the problem, I will first consider 4 areas: Window, Game, Toolbar and Misc. Within each of these I will identify the features relevant to that area and outline the information that is needed to create each feature in the actual solution. This information is represented in the table below, with the first column being the general area, the second being a more specific feature, and the third being the information about the feature.

C# is an object-oriented language, so everything in my solution will be built around objects. I will be making full use of this by creating custom classes for various features in the game.

WINDOW		
	BOARD	
		Draw bitmap of chess board
		Contained in custom container class
		Overrides OnMouseClick event
		Comprised of Squares (custom object) to store relative and absolute coordinates
	TOOLBAR	
		Displayed at top of window at all times
		Contains game settings (resolution, game restart, opponent settings) and help/tutorial
	HISTORY	
		Record every move and write to a text box
		Also saved to a file
		Displayed using algebraic chess notation[2]
		Clear on game restart
	BUTTONS	
		Redraw pieces to give impression of scrolling
		Pieces off the edge of the visible board are not drawn
		Board extends when scrolling at the edge of the current board
GAME		
	INITIALISE	
		Save data cleared, history cleared
		Board size is reset
		Board is drawn
		Pieces are drawn into starting configurations
	PIECES	
		Defined as objects with appropriate properties and methods
		Function to calculate and display available moves

		Function to move piece
	LOGIC	
		Turn system; white makes a move, and then black moves
		Only pieces of the colour of the current turn can be selected
		If AI opponent, calculate a response to the player and make a move
		If human opponent, give control to the opposite colour
		Check every turn if either king is in check or if the stalemate conditions are met
		If so, end the game
	MOVEMENT	
		Pieces show available movement when clicked
		Clicking another square will move the piece if possible
		Some situations will remove most possible moves (being in check, en passant), forcing the user to make a specific move or moves
		Cannot move King into check or checkmate
		Pieces can be moved further then the length of the board by scrolling after clicking the piece
	REWINDING	
		Will reset the board and game state to be as it was before the last move by both players
		Game state is saved to a file after every move; load data from file to achieve rewind
TOOLBAR		
	GAME	
		Start a new game; exit the game; request stalemate; forfeit game; rewind last move
	WINDOW	
		Change resolution; disable UI features (move history, movement indicator, pieces taken)
	SETTINGS	
		Change AI difficulty; change opponent; change amount buttons scroll by
	HELP	
		Tutorials for unorthodox pieces; explanation of features; general chess help
	ABOUT	
		Information about the program
MISC		
	SAVING	
		When the game is exited, game state is saved to a file and is loaded again next time the game opens

	DIFFICULTY	
		Difficulty controls how many moves in the future the AI will consider and the chance of the AI making the best move possible
	OPPONENT	
		The AI will only play if the option is selected, otherwise control will be given to the other colour piece at the end of the turn

Basic Classes

There are a number of key classes that will be used to form the structure of the game. Each class has properties and algorithms associated with it, which will provide a certain function for the game. Due to the nature of Windows Forms, the main loop is not written by me, and only deals with the actual window. The code I will be writing to create the game is event-driven, with most functions only being called as a result of a user interaction with the window.

chessWin

- Represents the actual window
- Execution of game begins in method `ChessWin()`
- Extends `Form`

ATTRIBUTE	TYPE	PURPOSE
`board`	`List<Square>`	A list of all the squares currently in the board
`pieces`	`List<Piece>`	A list of all pieces currently in play
`size`	`int[]`	The current dimensions of the board
`bounds`	`int[]`	Values representing where the edges of the board are
`origin`	`int[]`	The coordinates of the square 0, 0
`state`	`GameState`	The current state of the game

```
public chessWin() { //execution of game begins in this function
	state = initialising;
	InitializeComponent(); //added by the IDE, not written by me
	InitialiseBoard(); //Initialise attribute 'board'
	InitialisePieces(); //Initialise attribute 'pieces'
	drawGrid(); //draws the board and pieces after initialisation
}
public void InitialiseBoard() {
	for each square on the board graphic {
		board.Add(new Square);
	}
}
public void InitialisePieces() {
	for each piece needed for the game {
		pieces.Add(new Piece);
	}
}
public void drawGrid() {
	Graphics.Draw(bitmap of the chess board);
	foreach (Piece p in pieces) {
```

```
                Graphics.Draw(p.icon, p.x, p.y);
        }
        state = playing;
}
public void EvaluateCheck() {
        foreach (Piece in pieces) {
                if (piece = king) {
                        evaluate if the king is in check or checkmate
                        if so, state = blackwin or whitewin depending on which king
                        display the result
                 }
        }
}
```

Square

- Represents a square on the board
- Used to link absolute coordinates to a square on the board

ATTRIBUTE	TYPE	PURPOSE
X	int	The X coordinate of the top left corner of the square
Y	int	The Y coordinate of the top left corner of the square
indexX	short	The X index of the square on the board
indexY	short	The Y index of the square on the board

```
public static List<Square> emptyList() {
        return new List<Square> { }; //Used to initialise lists of squares so that
they can then be edited later
}
public override string ToString() {
        return each attribute separated by commas //Used so that we can display the
value of a square to a label which is useful for debug
}
```

GameContainer

- The control which will contain the chess board itself on the window
- Extends `Panel`

```
protected override void OnMouseMove(MouseEventArgs e) {
        //write the data of the square that the mouse is currently over to a label
        //this is useful for debugging many things throughout development
        Square cursorSquare = findSquareByCoords(e.X, e.Y)
        if (cursorSquare != null) {
                label.Text = cursorSquare.ToString();
        }
}
protected override void OnMouseClick(MouseEventArgs e) {
        //when the user clicks a square, try and find the piece that is on that
square, and then prepare to move the piece if applicable
        Square cursorSquare = findSquareByCoords(e.X, e.Y)
```

```
        Piece pieceClicked = null;
        foreach (Piece p in chessWin.pieces) {
            if (p.square == cursorSquare) { pieceClicked = p; }
        }
        if (pieceClicked != null) {
               draw movement for this piece
               state = moving;
        }
        if (state = moving) {
               move the selected piece to this square if valid
               state = playing;
        }
}
public static Square findSquareByCoords(int x, int y)
{
        //this is necessary so that we can find a square based on coordinates of
the cursor
        foreach (Square s in chessWin.board)
        {
            if (x >= s.X && x < s.X + chessWin.sf2 && y >= s.Y && y < s.Y +
chessWin.sf2) { return s; }
        }
        return null;
}
public static Square findSquareByIndex(int indexX, int indexY)
{
        //this is necessary for any function that does something to a piece (we
need to know where the piece is)
        foreach (Square s in chessWin.board)
        {
            if (indexX == s.indexX && indexY == s.indexY) return s;
        }
        return null;
}
```

Piece

- Represents a chess piece
- Makes use of 2 Enumerations:
  - `enum PieceType { pawn, knight, rook, bishop, queen, king, mann, hawk, chancellor, none };`
  - `enum PieceColour { black, white };`

ATTRIBUTE	TYPE	PURPOSE
type	PieceType	The type of piece this is
square	Square	The square the piece is on
icon	Bitmap	The icon of the piece
Colour	PieceColour	The colour (black/white) of the piece

```
public Piece(PieceType t, Square s, PieceColour c) {
        //the constructor for a piece; icon is not an argument in this
        type = t; square = s; colour = c; icon = link to icon based on type
}
```

```
public List<Square> calculateMovement() {
	//calculates the available moves for the piece and returns it as a list of squares
	if (type == none || type == null) return Square.emptyList();
	switch (type) {
		List<Square> movement = Square.emptyList();
		calculate movement for each type
		return movement
	}
}
public static List<Piece> InitialisePieces() {
	//stores the starting configuration of the board, which is then called at the start of the game
	List<Piece> pieces = new List<Pieces>;
	if save data exists, load that into pieces
	else
		Pieces.Add(first piece required);
		Pieces.Add(second piece required);
		 ...
	return pieces;
}
```

Program Logic

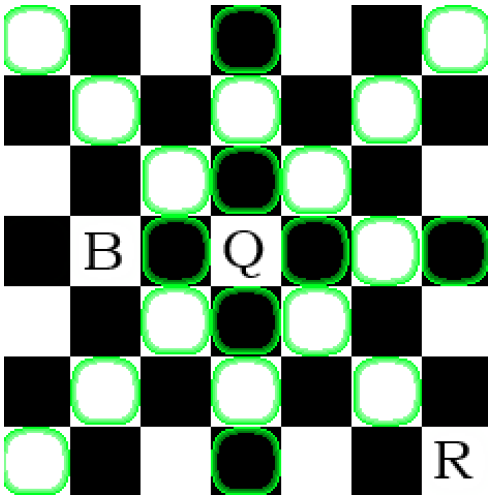
This represents the way the core feature (the chess game) will function from a computational view (as opposed to how the AI will function or how exactly every decision is made). This is the logical progression from function to function; which function is called as a result of a given event happening.

- `state` is set to init. Initialisation happens in `ChessWin()`, which sets up the game for the user to begin playing, as seen above. `state` is set to playing.
- Pressing a scroll button at any time will call the event `OnClick` for that button. For example, pressing the scroll up button will call the following function:

```
private void scrollUp_Click() {
   //first find the square which is in the top left corner
   Square edge = GameContainer.findSquareByCoords(0,0);
   //update the Y coordinate of each square and the origin
   O[1] += height of one square;
   foreach (square in the board) {
         square.Y += height of one square
   }
   //if the edge square has the same Y coordinate as the current upper Y bound, then add a new row to the board and update the bound
   if (edge.indexY == bounds[upper y]) {
       bounds[upper y] += 1;
       board.Add(new row above the old boundary);
   }
}
```

- Pressing somewhere on the board will call `GameContainer.OnMouseClick()`, for which the algorithm can be seen earlier on. If a square with a piece is clicked on, the available moves for that piece will be drawn to the screen and `state` is set to moving. To the right is an example of one design for this. The queen (Q)

has been pressed by the user, which can move any number of squares orthogonally. However, 2 directions are blocked by a bishop (B) and a rook (R). This affects the available moves for the queen, which are shown using the green circles. Clicking on one of these circles will move the piece to that location using `MakeMove(Piece p, Square location)`. `state` is set back to playing. Call `EvaluateCheck()` to check if either king is in check or if either player has won the game.



- If the opponent is AI, `MakeMoveAI()` is called to calculate an appropriate (not necessarily best, depending on difficulty) move to make. This move will be made and control will return to the player. If the opponent is human, the previous step is repeated but with control of the opposite colour pieces instead (e.g. `control = PieceColour.black;`). Call `EvaluateCheck()` again.
- Game logic is followed throughout the process of moves being made. After every move, the board state is saved to a file in `SaveData()` and the move history is updated with `History.Update()`.
- One of three things will happen; a player will win, a stalemate will occur, or the game will be closed. If either player wins or a stalemate occurs, the game state is set appropriately and a message is displayed informing the player what has happened. They can then start a new game which will put the program back into initialisation. If the game is closed then the game will resume where it was left off next time it opens in `InitialisePieces()`.

AI Logic

The first thing an AI for chess must be able to do is get a list of all moves available for every piece of one colour. This can be achieved using the function seen earlier `Piece.calculateMovement()`:

```
public List<string[]> calculateAllMovement(PieceColour c) {
	//create an empty list for the moves
	List<string[]> result = new List<string[]>;
	foreach (Piece p in pieces) {
		if (p.colour == c) {
			p.calculateMovement();
			//add each move for each piece to the list
			foreach possible move {
				result.Add(new string[] {coordinates of p, coordinates
of move})
		}
	}
	return result;
}
```

The simplest AI one could make is to simply select a random move from all possible ones. This will give something that you could play against, but it will be ineffective as it will make no attempt to actually win the game.

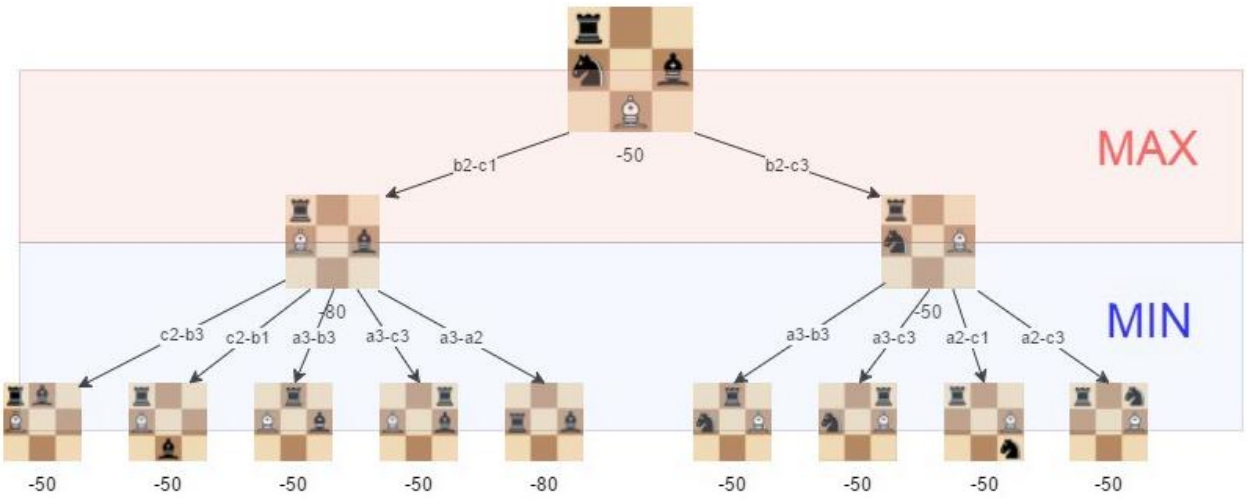
To improve this, we can decide on a metric that the AI can use to evaluate the state of the board in terms of which side is in a better position. This is the basis for many chess AIs, and is just as applicable in the infinite variant. This method works by assigning each piece of your own colour a positive value based on how useful the piece is, and each opposing piece is given a score of equal magnitude but negative. Summing the scores of every piece on the board gives a basic metric for the state of the game. An AI can then use this and select the move which gives the highest positive value. Example values for pieces are in the table below.

PIECE	SCORE
Pawn	1
Mann	2
Bishop	3
Knight	3
Hawk	4
Rook	5
Chancellor	7
Queen	9
King	50

However, all this effectively does is make the AI capture a piece if it can. Otherwise, it still just picks moves at random, which is still not an effective strategy.

The next way the AI can be improved is by searching future moves and evaluating these in the same way. Making use of the minimax algorithm will allow the AI to actively select moves that will lead to a favourable game state.

The minimax algorithm recursively searches a tree of moves and evaluates a score for each node using the same method as above. At each layer, the best move is decided by looking for either the minimum or maximum value of the child nodes. Whether we are maximising or minimising depends on the player that would be playing on the turn we are considering. Below is an image[1] which visualises this.

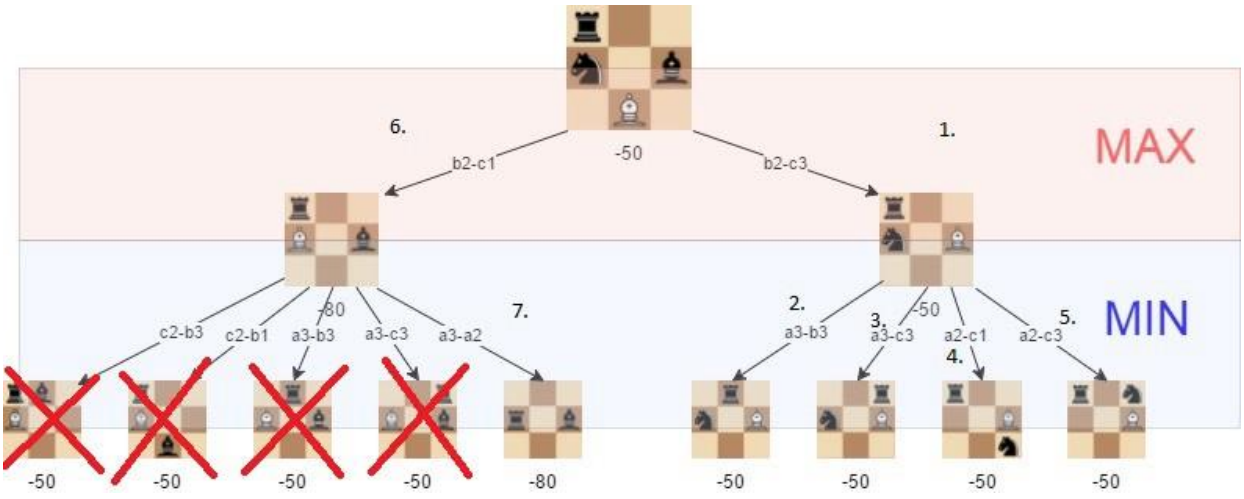


Given the 3x3 state seen at the top of the image, the minimax algorithm would return b2-c3 as the best move (the one on the right) because this will guarantee a minimum score of -50, whereas the other move could end up scoring -80. The minimum score

for white has been maximised. This algorithm will be as effective as the search depth we give it. Pseudocode for this algorithm:

```
function int maxi(int depth) {
	if (depth == 0) return evaluate();
	int max = -9999;
	for (all moves) {
		score = mini(depth - 1);
		max = math.max(score, max)
	}
	return max;
}

function int mini(int depth) {
	if (depth == 0) return -evaluate();
	int min = 9999;
	for (all moves) {
		score = maxi(depth - 1);
		min = math.min(score, min);
	}
	return min;
}
```

There are some ways this algorithm could be improved further. Alpha-beta pruning can be used to search with more depth using the same amount of resources. In the



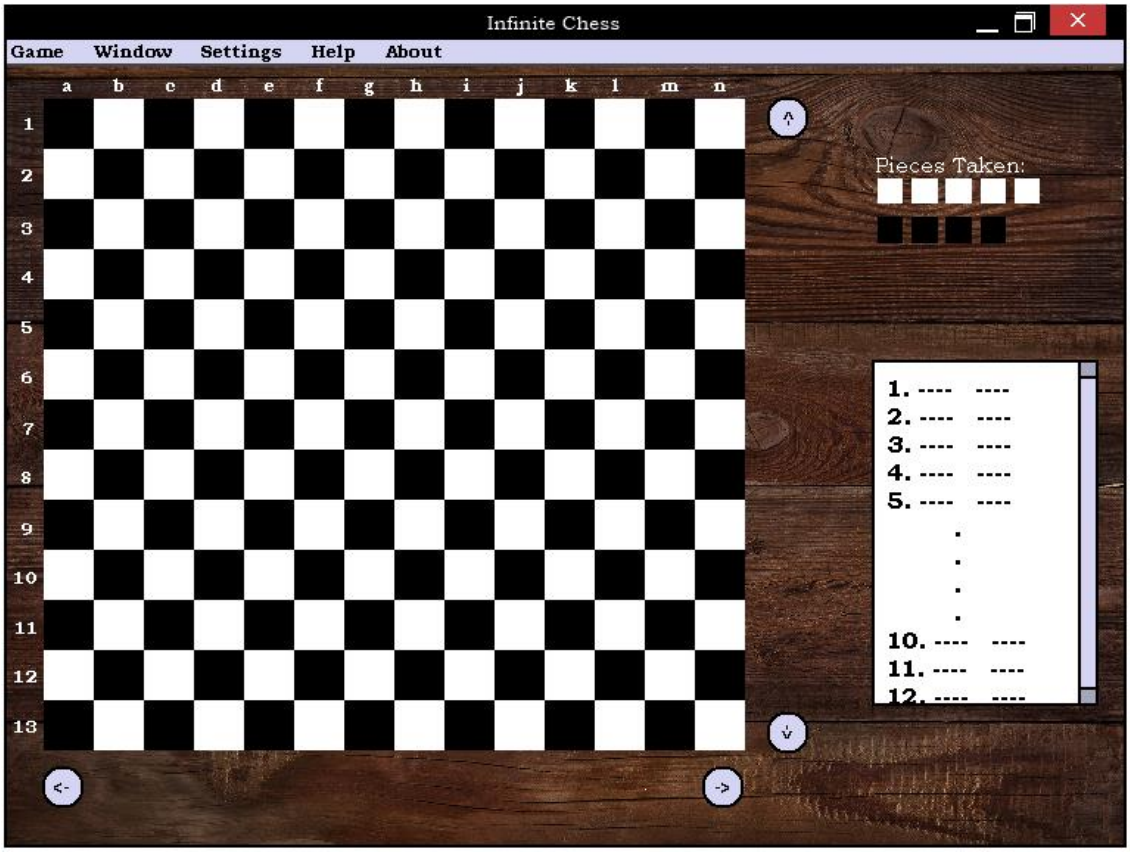
example seen here, if the algorithm visits each node in the order they are labelled, we know that choosing b2-c3 will provide a minimum of -50. As soon as we consider the first node of the left path, we see it is -80 and therefore the minimum for this side is lower. This means we do not have to consider any of the remaining nodes on the left side, thus saving computation time.

Rather than assigning static values to each piece, we could add some variance based on the environment of the piece. In regular chess, this can be done by defining an 8x8 table of values, and then multiplying the value of the piece by the corresponding value in the table when the piece is on that square. In infinite chess, it is not possible to define an infinite table, so any dynamic values will need to be based on the pieces

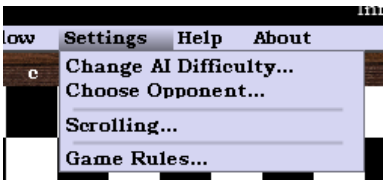
nearby. For example, a queen protected by a rook could be worth 10 instead of 9, which would cause the AI to play in such a way that its queens won't be easily taken.

Window Design

The features that will be needed on the window are the board, scroll buttons, toolbar, move history, pieces taken and labels. Below is a design for the window.



In this design, the visible board is 13 by 14 squares. This is subject to change, as I will need to test what size squares will give the best balance between graphical quality and amount of information available.

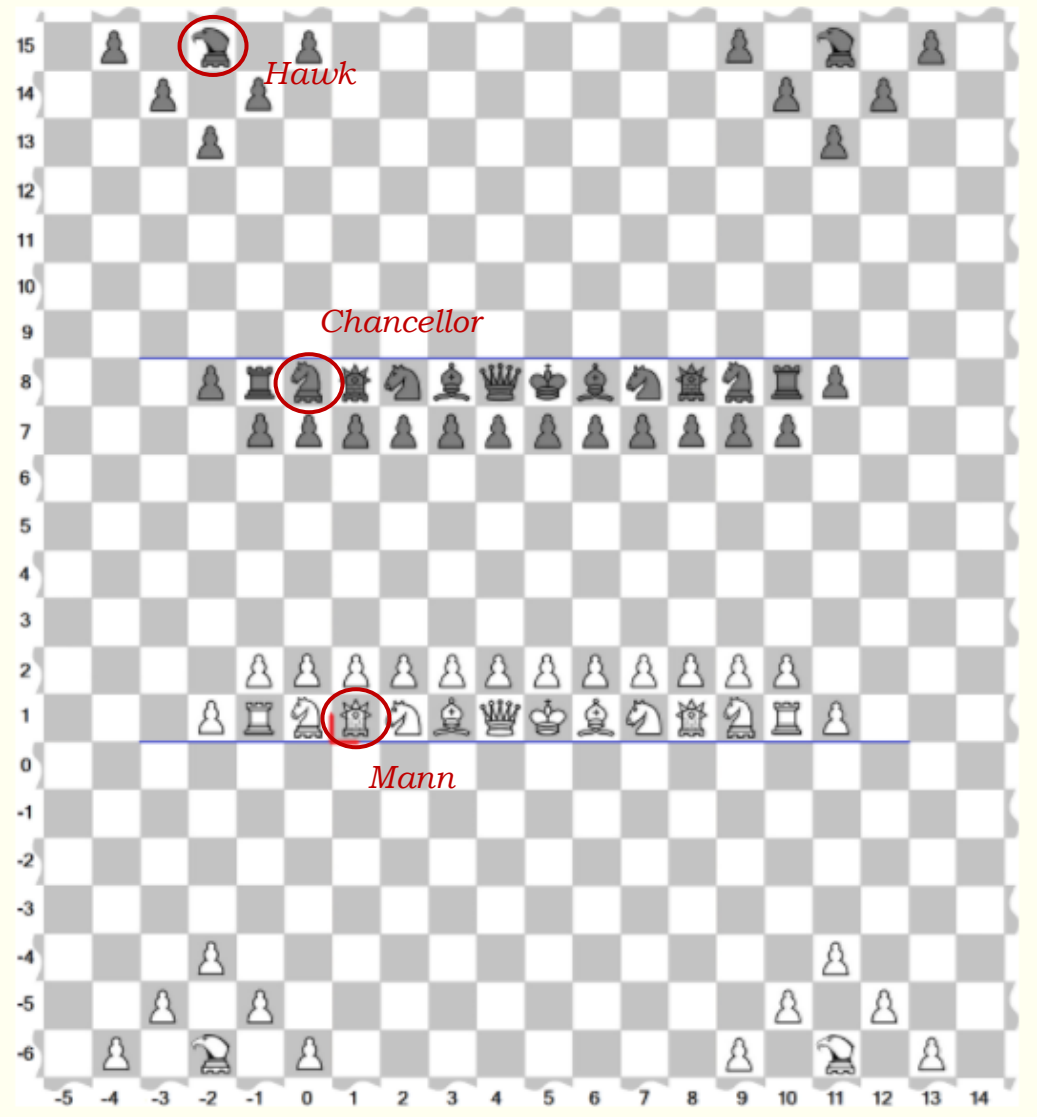


The move history is a scrolling textbox seen on the bottom right, with 1 move per line. Again, testing will need to be done to adjust the font size so that it is readable, but shows enough information to be useful. Pieces taken will simply be a label with the icons of pieces that have been taken on each side. The scroll buttons are seen to the left and below the board. I feel the positioning and text of the buttons makes what each will do intuitive. The design of the toolbar buttons can be seen on the right; it's just a standard toolbar.

When it comes to changing resolutions, my plan is to have the same ratios for size of each control on the screen (i.e. each control takes up the same amount of space relative to the window size), however, the board will be able to have a higher density of squares. This means that there is an advantage to playing with a higher resolution monitor, rather than everything being static.

Game Design

The starting configuration for infinite chess is seen below (from chessvariants.com).



This is clearly rather different to the starting configuration for regular chess, and contains some unusual pieces. The piece seen near the corners of the board behind the pawns are known as Hawks, and they move either 2 or 3 squares in any orthogonal direction, and is able to jump over other pieces. One piece inward from the rooks are the Chancellors, which have the movement of a rook and a knight combined. Another piece inwards are the Manns, which have identical movement to a King, but are not affected by check.

Game Rules for Infinite Chess:

- Pawn promotion still occurs in this variant of chess. White pawns promote at rank 8, and black at rank 1.
  - Pawns can promote to hawks, chancellors or manns in addition to the regular pieces.
- Castling is not a valid action.

- The fifty-move rule does not apply.
- All other rules are the same as for regular chess.

Move notation differs slightly from regular chess. This is relevant because I will be displaying a move history using the appropriate notation. Examples of notation for infinite chess are as follows:

A queen moves from (6,-3) to (10,-3)	*Q(6,-3)-(10,-3)*
A rook captures the piece at (5,-2) from (5,6)	*R(5,6)x(5,-2)*
A pawn promotes to a chancellor at (8,2)	*(8,3)-(8,2)C*
A knight moving to (5,-4) causes check	*N(3,-5)-(5,-4)+*

Testing Overview

As this is an iterative development process, I will be testing code as it is written to ensure it works as expected. A sizeable portion of my code is functional which will allow for easier testing. Visual Studio also has a variable watch feature will can allow me to see the values of my variables while the program is running. Throughout the process, I will screenshot blocks of code as they are written, then test and debug them with input data, expected results and actual result. I will also refactor previous code to become more efficient if necessary or I think of a better way to perform a task.

Example testing:

- scrollUp Button
  - Press the button once and observe what happens. The expected result is that all pieces on the board move down by one square, the bounds of the board extend if necessary, and the coordinates of each visible square have changed.
- GameContainer.OnMouseClick()
  - Click on any piece on the board. Output each attribute of this piece to a label on the form. The expected result is the name of the piece type, the square it is on, and the colour of the piece.
- Piece.CalculateMovement()
  - Click on a queen piece with various other pieces surrounding it. Observe the squares highlighted. The expected result is there is a line of available moves in each orthogonal direction, up until another piece gets in the way, and no squares highlighted after such obstructions (as seen in the screenshot earlier).

When the game is in a playable state, I can ask my client and other chess players to play against the AI or each other to see if the game plays as it should to them. This black box testing is useful because I am not an experienced chess player, so I am not the best judge of how difficult a given chess AI is to play against.

Testing Details

For some large features of the program, I will undertake extended testing after development is finished to ensure each section is working. I will also conduct an overall test after development is complete.

Scrolling Tests

After scrolling the board has been implemented, I will test whether it is working correctly. This will involve using a debug label to view the coordinates of a given square. I will then press a certain sequence of scrolling buttons which will be recorded, the expected result will be calculated, and then compared to the observed result. If all the results match, I can be sure that scrolling will work.

For example, the square that is at coordinates 0,0 will be at 1,1 if the scroll up and scroll right buttons are pressed.

Initial Piece Movement Tests

The first iteration of piece movement calculations will not take into account check or checkmate, as these features will be developed after piece movement is completed. This testing will be done as a series of screenshots of different scenarios, with at least one for every piece. For each test, the piece to be clicked will be stated, along with the expected outcome, and then whether the result was expected or not. Screenshots of the actual outcome will also be included.

For example, I would expect the movement of a rook to stop at a piece that blocks its line of movement.

Updated Piece Movement Tests

The final iteration of piece movement tests will take into account check and checkmate. This means that pieces will not be able to move to squares which would put their king in check, and if their king is already in check, only moves which will move it out of check are valid. This will need to be tested to ensure every piece is having movement altered correctly to account for these possibilities.

For example, a king with an enemy rook directly above it should not be able to move straight down, since this would not remove it from check.

General Gameplay Tests

This section of testing will be undertaken after many of the features that are not directly gameplay have been added. For instance, undoing moves, the move history, the menu bar, and others (these are listed in the decomposition). I will conduct testing that will involve gameplay combined with one of these other features to ensure that they work together as expected.

For example, a white pawn that reaches row 11 should be given the option to promote to another piece.

AI Testing

This section will be completed after the AI has been developed. The AI will be an integral part of the game, so thorough testing will be necessary. I will want to ensure that it is easy to use, works to a reasonable standard, and does not have any unexpected behaviour.

For example, I should not be able to control or move any of the AI's pieces at any time.

Post Development Testing

This testing phase will be part of the evaluation section. As the name suggests, it will be completed after development has finished, and it will consist of multiple tests which use a range of the different features of the game. As before, this is to ensure that all features work correctly with each other, but this time it is also to test that the game feels like a finished product and not just a tech demo.

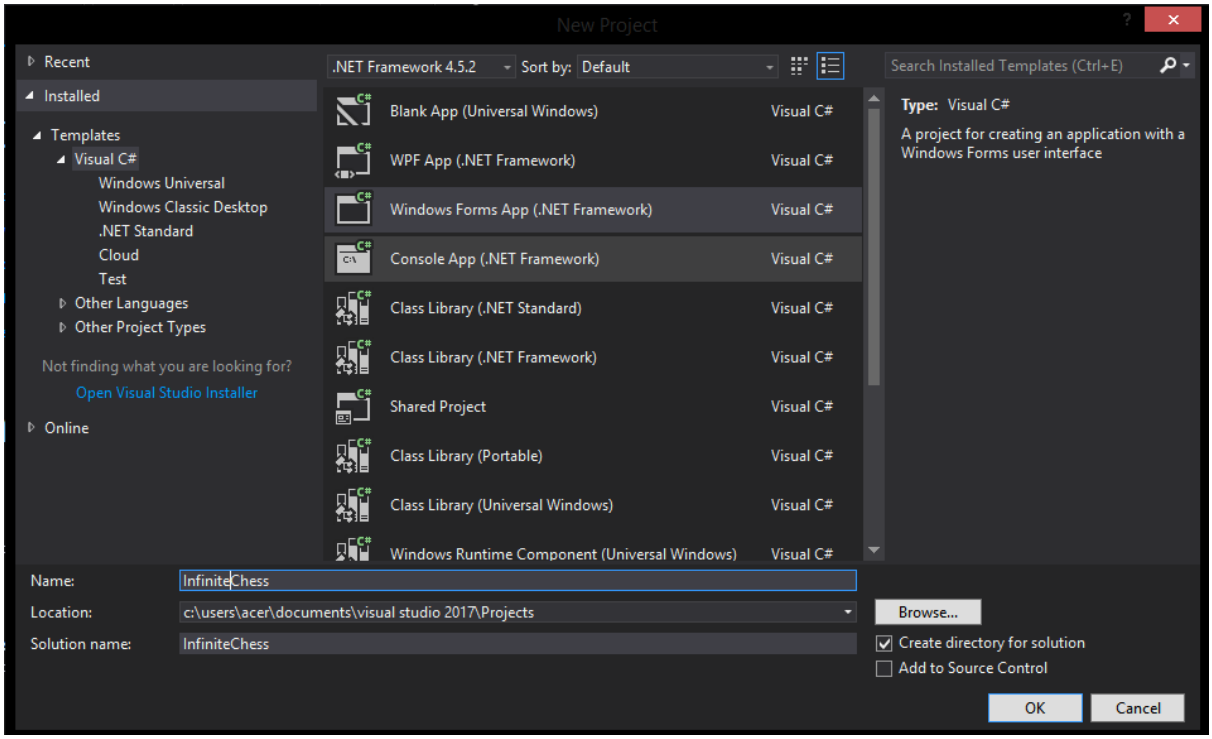
For example, I will play a full game of chess against the AI, combined with undoing moves and changing the window resolution.

After each testing section, I will analyse the results of the tests and decide what action needs to be taken. If all tests are successful, then I can conclude that part of the game is working correctly, and I can move on. If some tests give unexpected results, I will be able to identify the problem in my code and fix it before moving on.

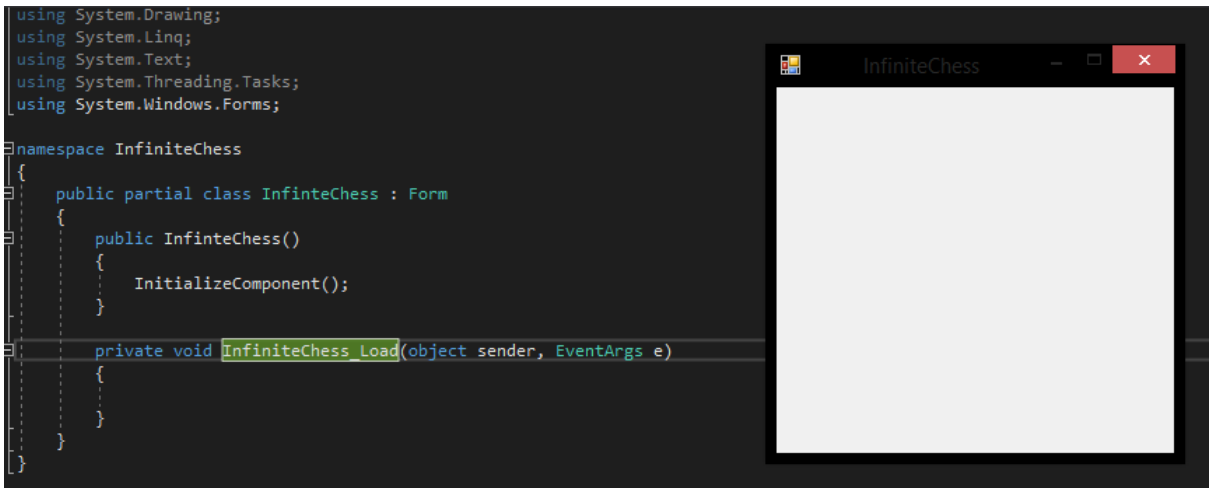
Section 3: Development

Project Creation

I am using Visual Studio to develop this game. The first step is to create a new Windows Forms Project.



This creates an `InfiniteChess : Form` class, which is just an empty window with no components. This is what I will build the game upon.



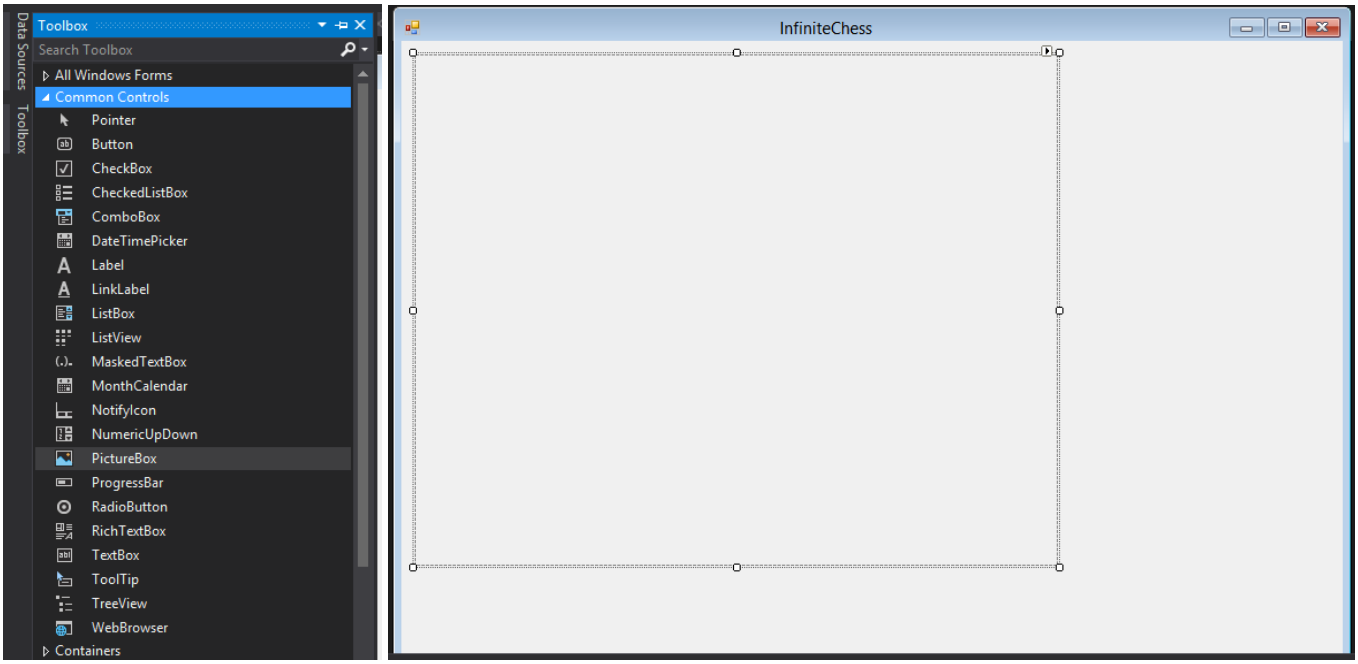
Creating the Board

The first thing I need to figure out is how to actually get a chess board onto the window. I will change the size of the window to 864x720 so that it is big enough to display an image, but not so big that it cannot fit onto the 720p screen of my laptop.

One approach I could use is draw a board manually using `System.Graphics`, and drawing each square on the board separately. This would need to be stored as an array of `Rectangles` (a built-in type for graphics). However, I also need to store another array of `Squares` anyway to hold the other data for each square of the board. This would mean I have to work with two separate arrays, one holding graphics and the other data, which need to be able to be linked to each other.

However, this is unnecessarily complicated if you consider the movement of the board itself. The only difference between this program and regular chess when it comes to the board is the need for it to scroll. If you were to scroll the board in any direction by one unit, every square you can see would take on the opposite colour. As a result, moving two units in any direction will leave the board visually unchanged. This means that if any scrolling is done in multiples of two units, the board will always look the same, and therefore the board does not to be redrawn on every scroll. So instead of constructing a board manually, drawing an entire image from a file will increase the efficiency of the program and reduce the resources required.

To get an image onto the window, I will need a `PictureBox` control, which I can select from the Toolbox and drag onto the window.



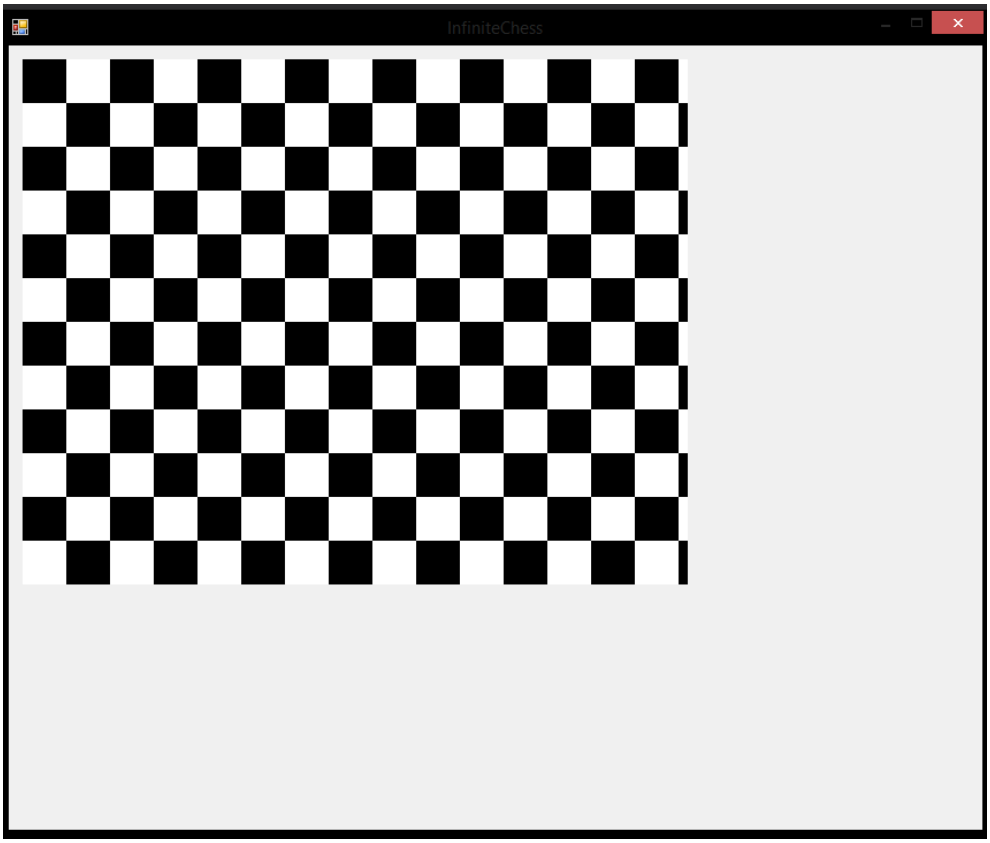
The window now has an empty `PictureBox` on it. The image displayed is a property of the control; to set this property I can set it in the visual editor to an image, or I can set it within the code. Since I may want to change the image later on during program

```
private void InfiniteChess_Load(object sender, EventArgs e)
{
    board.Image = new Bitmap("res/image/board.png" + "");
}
```

execution, it would be more logical to write the code for it. I have named this instance `board`, so I can now use the following code to set its image.

`Bitmap` is a built-in class which handles images. In this case, I am using its constructor which takes a file path as an argument. `res` is a folder I have created to house all the resources the game will need (further on graphics for things such as pieces will be needed). `board.png` is an image file I created which is just a simple checkerboard pattern. `InfiniteChess_Load` is an automatically generated method for the event which is called after the window has finished loading. Windows forms programming is largely event-driven; double-clicking on a control in the design view adds a new method which is called when the main event tied to that control occurs. For example, double clicking on a `Button` will generate a method which is called when the button is clicked.

Running the code as it is now causes the following window to appear. This is not quite what one would expect a chess board to look like; some of the squares have been cut off.



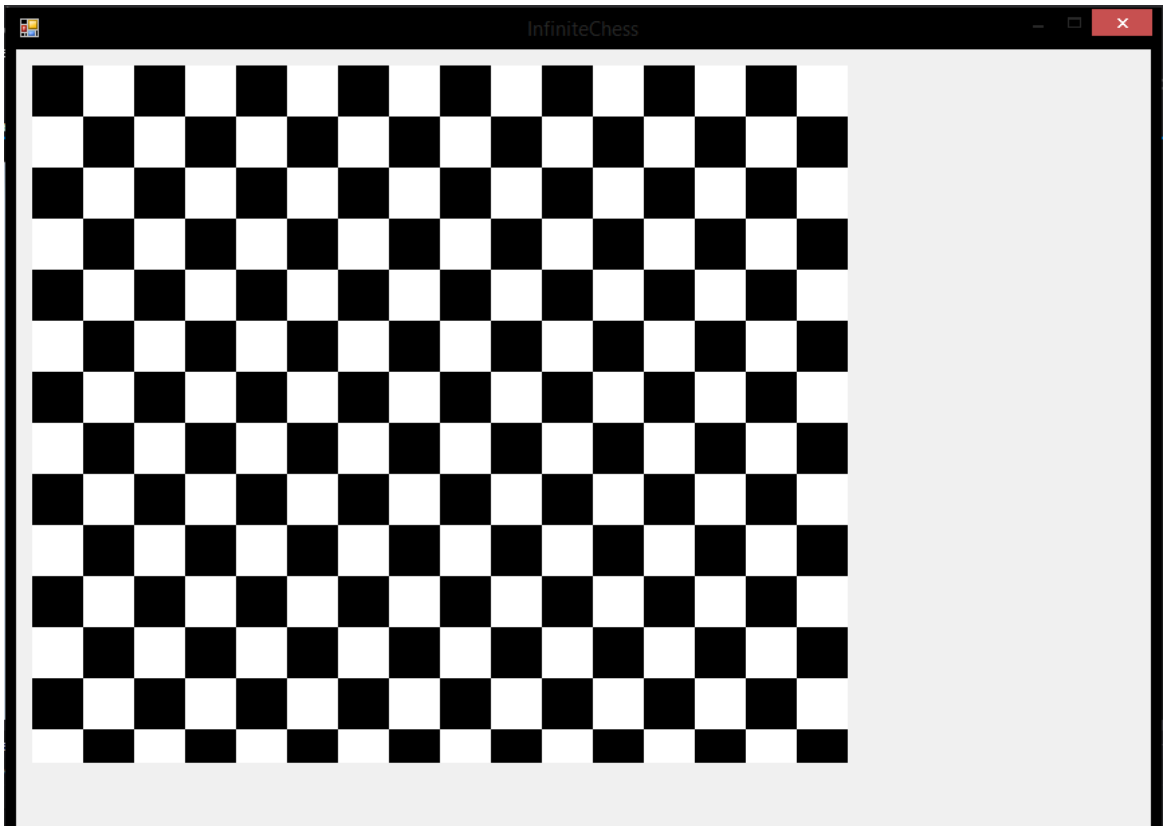
At this point, I have also realised another problem with what I have done so far. If I use a `PictureBox` for the board, I will not be able to draw pieces over the top of it without using another `PictureBox` for each piece because of how Windows Forms decides which controls are on which layers. To get around this, I will use the `Panel` class instead and will draw my own images using `System.Graphics`. As per my design section, I already know I will want to override the functions `OnMouseMove` and `OnMouseClick` from `Panel`, so I will create a custom class which extends `Panel` called

`GameContainer`. To make it easier for me to navigate my code, I will create this in a new file called `Classes.cs`, where I will also put my other classes later.

```
Classes.cs | InfiniteChess.cs | InfiniteChess.cs [Design]
InfiniteChess | InfiniteChess.GameContainer | OnM
1  using System.Collections.Generic;
2  using System.Windows.Forms;
3  using System.Drawing;
4
5  namespace InfiniteChess
6  {
7      class GameContainer : Panel
8      {
9          protected override void OnMouseClick(MouseEventArgs e)
10         {
11             Graphics g = CreateGraphics();
12             g.DrawImage(new Bitmap("res/image/board.png"),0,0);
13         }
14     }
15 }
16
```

I have overridden the method `OnMouseClick` to draw the image of the board on the panel at 0,0. This will allow me to test if this class is implemented correctly. I will create a new instance of `GameContainer`, called `boardPanel`, in the design tab and then run the program. After clicking the panel, an image of the board should appear.

Clicking the panel causes the following to happen:



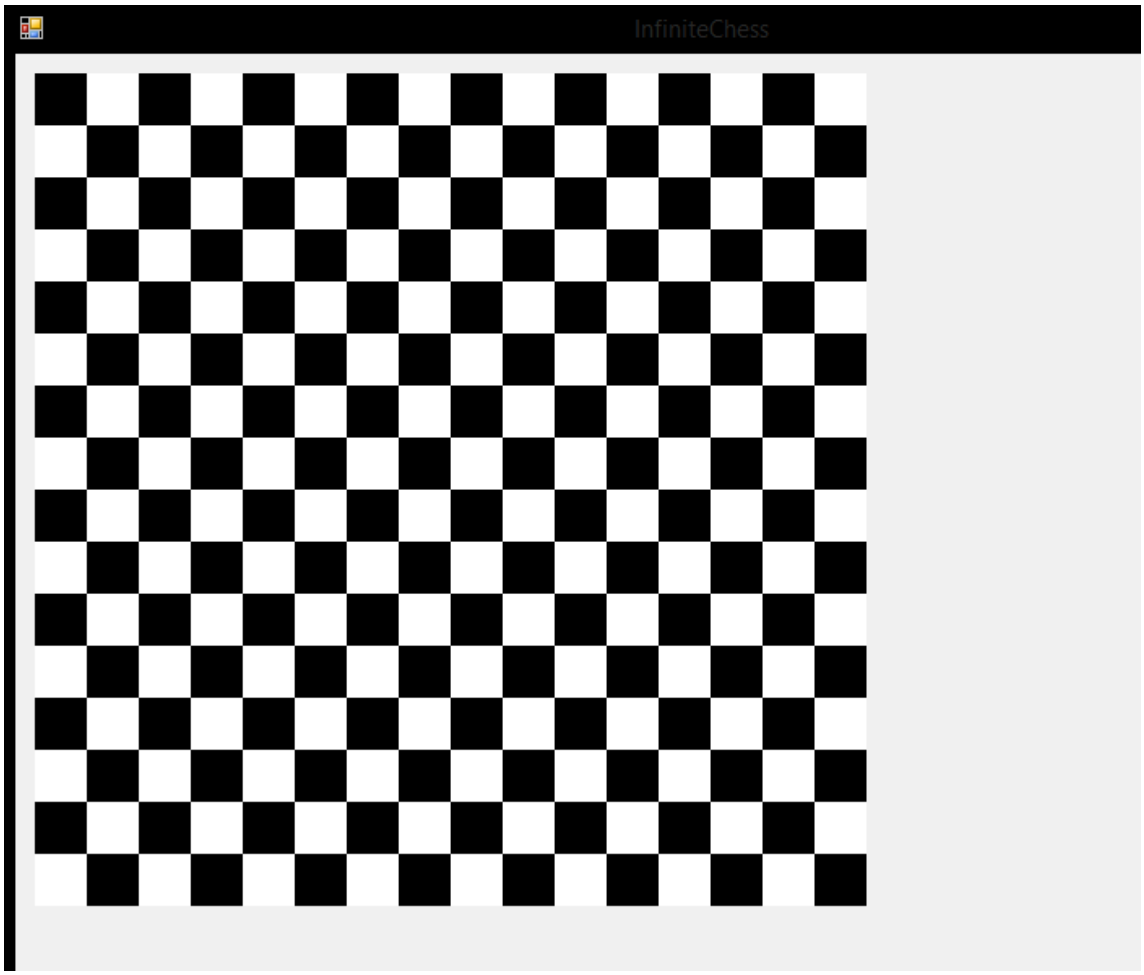
This means the class has been implemented correctly and I can now build upon it.

Currently, the board isn't being drawn quite how I want it; there are still some squares being cut off. However, since I'm using `Graphics` to draw it, I can specify the size of the image to draw. When using `Graphics`, the coordinates used are based off the control the instance of Graphics was created in. In this case, the coordinates 0,0 are the top left corner of `boardPanel` (not the top left corner of the whole window). One convenient property of this is drawing something with coordinates which are outside the control will simply not be drawn. This means that if I specify a size for the image which is larger than the size of `boardPanel`, I can magnify the board.

For now, I want the board to be 16x16 squares, which is the size of the actual image. If each square is 32x32 pixels, the entire `boardPanel` will be 512x512, which fits on the current window, so this is the size I will use for now. The previous code will be updated to reflect the new size we want:

```
protected override void OnMouseClick(MouseEventArgs e)
{
    Graphics g = CreateGraphics();
    g.DrawImage(new Bitmap(new Bitmap("res/image/board.png"), new Size(512,512)), 0, 0);
}
```

Running the program and then clicking the panel yields the following:



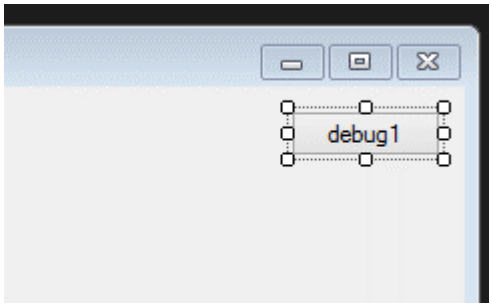
This is a 16x16 grid of complete squares with a size of 512x512 pixels.

Adding Board Functionality

Now that I have a grid, a way to store data about the board is needed. As mentioned in the Basic Classes section, I will be using the class `Square` to describe the pixel coordinates of each square. I will create the `Square` class in Classes.cs:

```
public class Square
{
    public int X { get; set; }
    public int Y { get; set; } //actual coordinates
    public short indexX { get; set; }
    public short indexY { get; set; } //square reference
    public static List<Square> emptyList() { return new List<Square> { }; }
    public override string ToString()
    {
        return indexX.ToString() + ", " + indexY.ToString() + ", " + X.ToString() + ", " + Y.ToString();
    }
}
```

I now need to create the `InitialiseBoard()` function, which will use a `List<Square>` to represent the board. To do this, two nested `for` loops will be required. Since all this function will do is add some elements to a list, there is no visual feedback that it is working correctly. As a result, I will use `Graphics` to draw something on each square that is created so that I can ensure it is functioning correctly.

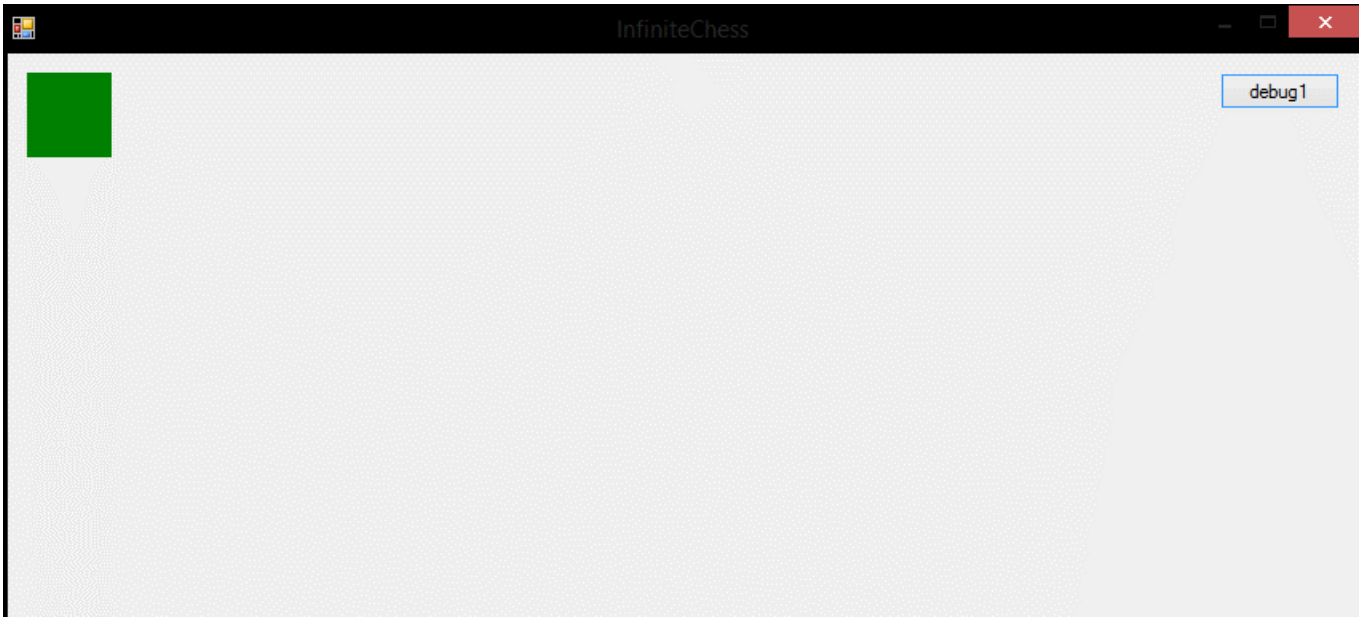


At this point, I will also add a debugging button to the form. This will be useful because I can test out specific functions by just assigning them to this button. For now, I will assign `InitialiseBoard()` to this button, so that whenever I click it, `board` will be populated.

```
//create the logical board
public void InitialiseBoard() {
    Graphics g = boardPanel.CreateGraphics();
    for (int i = 0; i < 16; i++) { //columns
        for (int j = 0; j < 16; j++) { //rows
            board.Add(new Square { X = 38 * i, Y = 38 * j, indexX = (short)i, indexY = (short)j });
            g.FillRectangle( new SolidBrush(Color.Green), i, j, 38, 38);
        }
    }
    g.Dispose();
}
```

Each loop repeats 16 times, which will create a board of size 16x16 squares. `board.Add()` takes a `Square` as an argument, and the constructor for `Square` takes an x-coordinate, a y-coordinate, an x-index and a y-index. The indexes for each square are simply the `i` and `j` values used in the loops. The coordinates for each `Square` is calculated by multiplying the `i` or `j` value by 38. This should give squares of size 38x38 pixels.

Running the program and pressing the button yields the following:

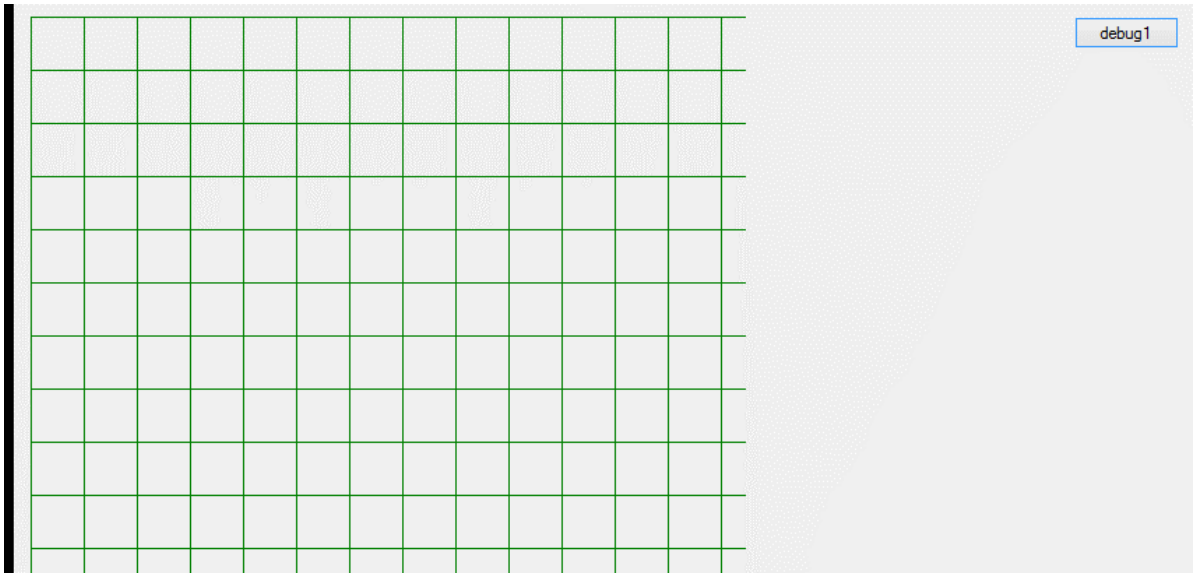


This is not quite the expected outcome. It appears to have only draw a single square. However, this square is clearly larger than 38x38 pixels. Looking at my code once again, I see that in `FillRectangle`, I have provided `i, j` as the first and second arguments. These arguments define the coordinates of the top left of the shape to draw. Since the maximum value of these 2 arguments is 16, it is drawing the correct number of squares, but all in the top left corner. Multiplying these two arguments by 38 (the size of the squares) should resolve this problem.

Another problem I have noticed is that I cannot distinguish between squares with this method of drawing. This function will just draw a large green square of size (16*38), which is not helpful at all. To fix this, updating the last line to draw outlines of rectangles instead of full rectangles will be enough:

```
g.DrawRectangle( new Pen(Color.Green), 38*i, 38*j, 38, 38);
```

Running this function now displays the following:



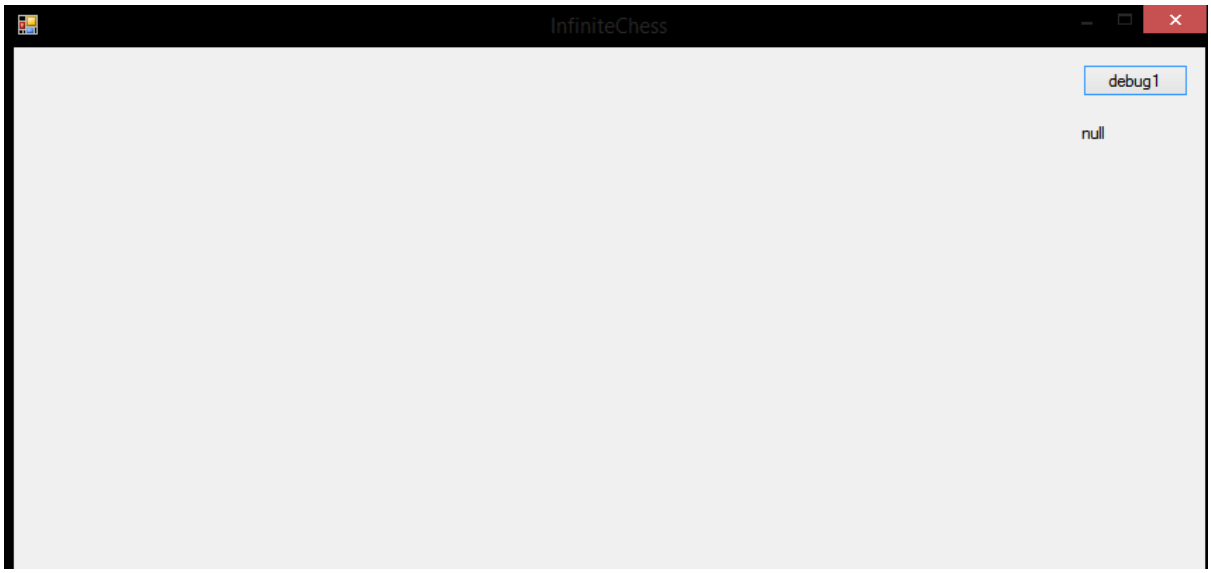
A grid of squares, which is what we wanted. I can see that the structure of the List is correct as a whole, but I still can't tell if each individual square is where I expect it to be. To do this, I will need some way of outputting the attributes of each `Square`. The best way to do this would be to use a debug label and have the `OnMouseMove()` function display information about the `Square` the mouse is over in the label. First, I need a way to find a `Square` given its coordinates (which are passed in from `OnMouseMove()`). This will be a function in `GameContainer`, because it will then be easier to use this function inside other methods in `GameContainer`.

```
public static Square findSquareByCoords(int x, int y) {
    //iterate through each square
    foreach (Square s in InfinteChess.board) {
        //determine if the passed in coordinates are in the boundaries of the square
        if (x >= s.X && x < s.X + 38 && y >= s.Y && y < s.Y + 38) return s;
    }
    return null;
}
```

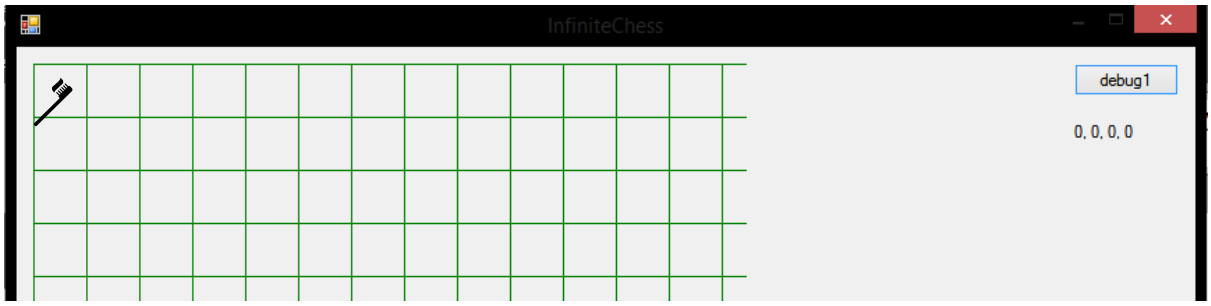
And then to set up the label, which makes use of my overridden `Square.ToString()`:

```
protected override void OnMouseMove(MouseEventArgs e)
{
    Label l = (Label)Parent.Controls.Find("debug2", false)[0];
    Square cursorSquare = findSquareByCoords(e.X, e.Y);
    l.Text = cursorSquare?.ToString() ?? "null";
}
```

This code should display the 4 attributes of the `Square` the cursor is currently over in the debug label, and it should display "`null`" if there is no `Square` where the mouse cursor is. Now I can check if each `Square` is where I expect it to be.



Before anything has been generated, the label displays `null`, which is the expected outcome since there are no `Squares` yet.



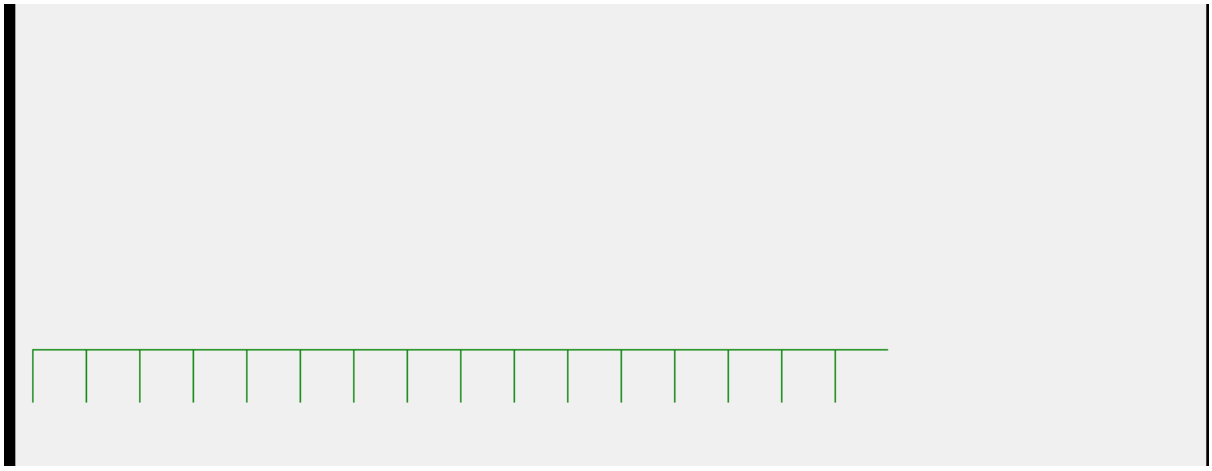
However, there is a problem here. My cursor is over the top left square, but this square has index [0,0] according to the label. This is because coordinates are labelled from the top left of an object (so this square also has coordinates (0,0)), but I want the indexes to start from the bottom left. This means I will need to adjust the code for initialising the board so that [0,0] is where I want it.

Note: square brackets [] will be used to refer to an index, parentheses () will be used to refer to coordinates

The bottom left corner in a 16x16 grid is at (0,570), so we need to make sure [0,0] is there. I will store the coordinates (0,570) as a variable so that I can adjust this later if needed. I can then use the variable in the board generation code to move [0,0] to (0,570).

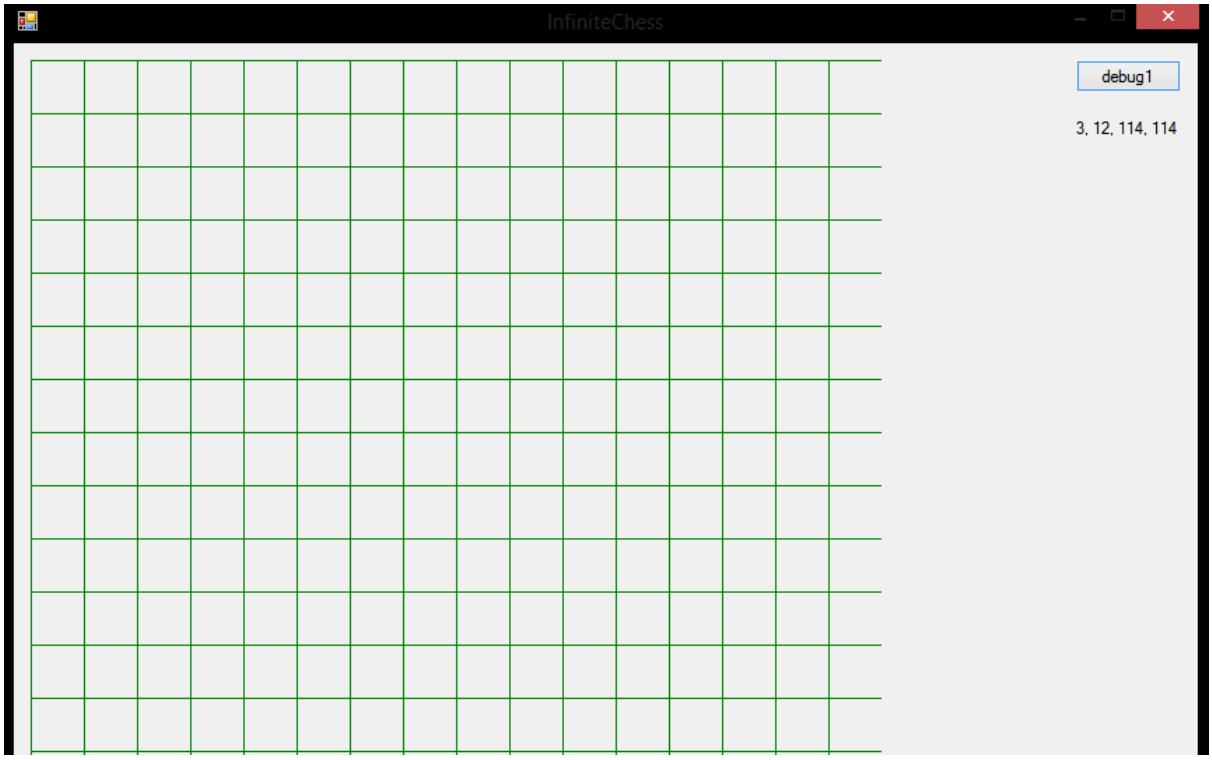
```
board.Add(new Square { X = origin[0] + 38 * i, Y = origin[1] + 38 * j,
```

By adding 570 to each Y coordinate, I effectively move every square down by 16 squares, which means [0,0] is now at (0,570). However, most of the squares are now off the screen since the positive Y direction is still down rather than up, as seen below.



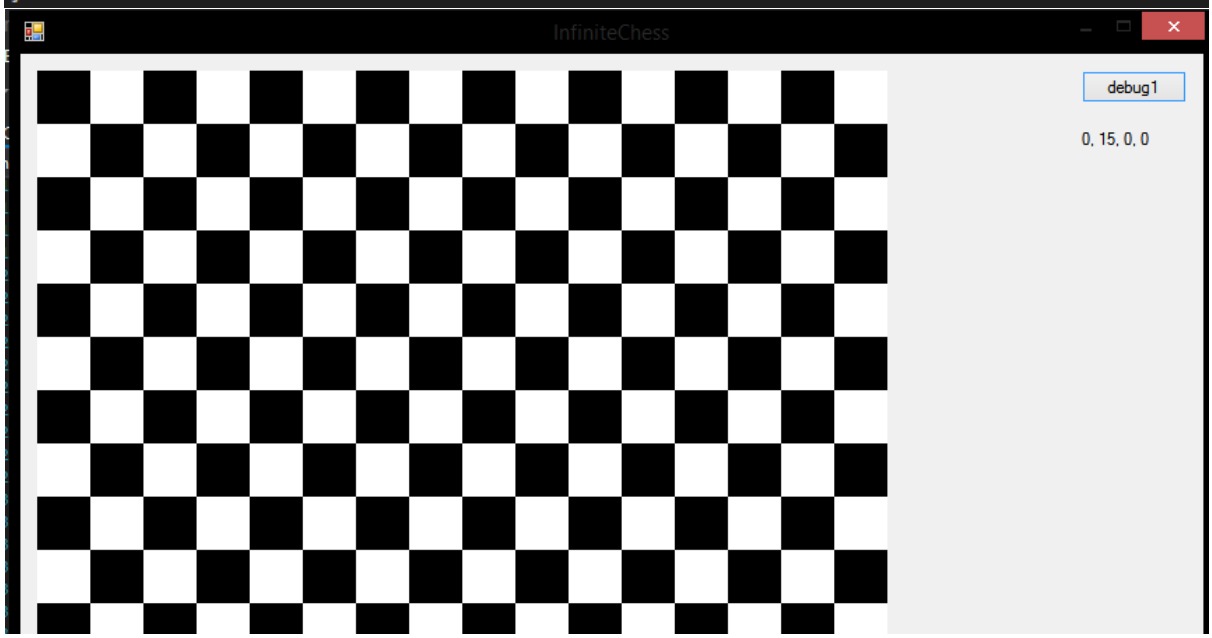
To fix this, `38*j` needs to be subtracted from `origin[1]` instead of added. This reverses the Y direction for indexes, which will give the desired result; [0,0] is in the bottom left and [15,15] is in the top right.

```
board.Add(new Square { X = origin[0] + 38 * i, Y = origin[1] - 38 * j,
```



To complete this, I just have to draw the board image over the Squares, and then I will have a regular chess board of size 16x16:

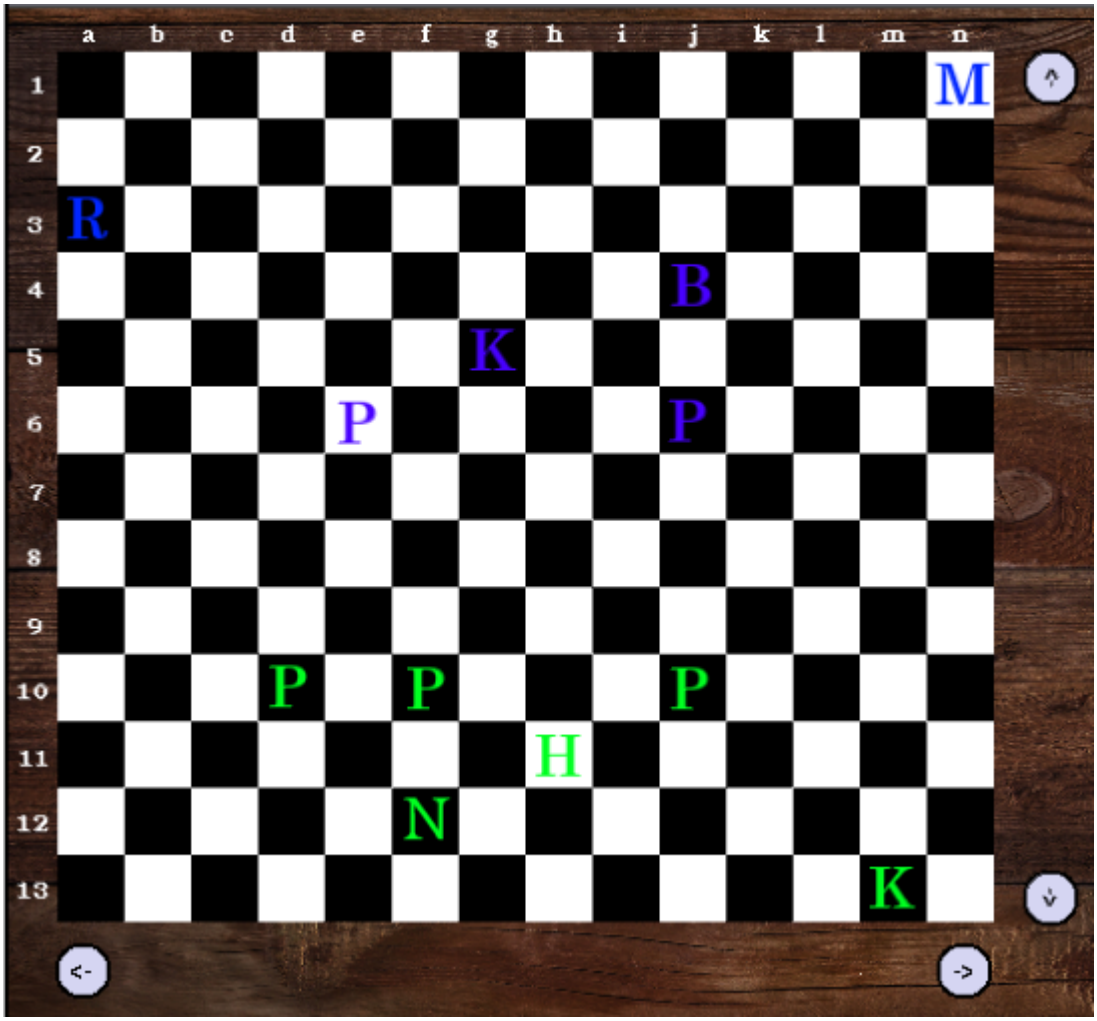
```
public void InitialiseBoard() {
    Graphics g = boardPanel.CreateGraphics();
    g.DrawImage(new Bitmap(new Bitmap("res/image/board.png"), new Size(608, 608)), 0, 0);
    for (int i = 0; i < 16; i++) { //columns
        for (int j = 0; j < 16; j++) { //rows
            board.Add(new Square { X = origin[0] + 38 * i, Y = origin[1] - 38 * j, indexX
            //g.DrawRectangle( new Pen(Color.Green), origin[0] + 38 * i, origin[1] - 38 *
        }
    }
    g.Dispose();
}
```



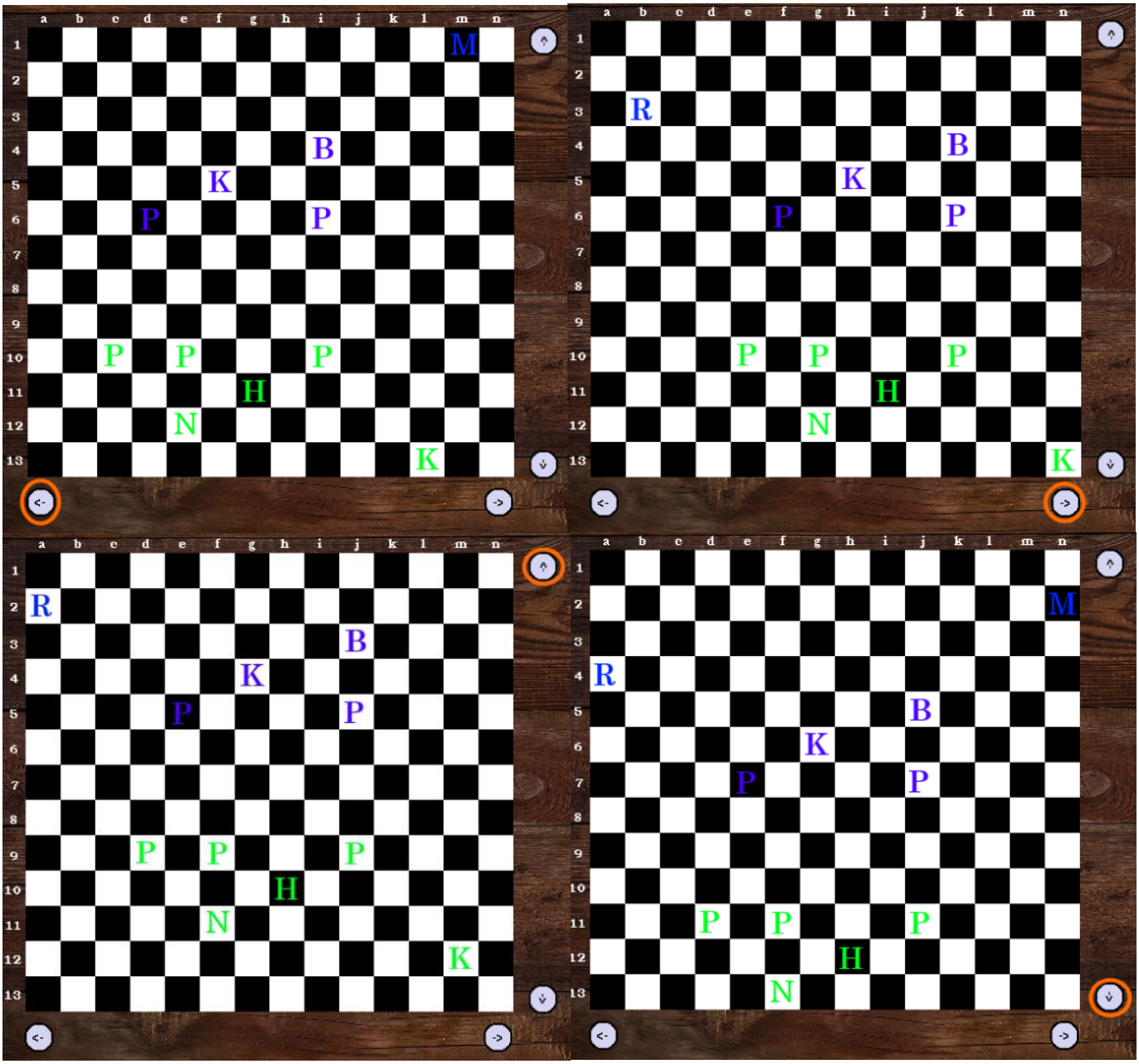
The Infinite Board

This is infinite chess, not regular chess, so simply drawing a 16x16 grid is not enough to be able to progress further in development. I need to implement a board with an infinite nature, and clearly I cannot display anything with infinite size. This will be circumvented by being able to scroll the board across the screen to access the rest of it. In reality, the board cannot actually be infinite because any computer system only has a finite amount of memory, but it can be made large enough that it will be effectively infinite.

Here is a sample board configuration with the pieces being blue and green, with scroll buttons:



The following images show the new state of the board if the highlighted scroll button is pressed:



As can be seen, scrolling the board can cause pieces to become out of view. They still exist and scrolling the board back to them will cause them to reappear.

As seen earlier, the board is represented as a `List<Square>`. For the finite 16x16 board, this list contains 256 elements. For the infinite board, it will be much larger, depending on what I decide the size should be. However, defining all these `Squares` at the start of the program would be an inefficient use of memory, because chances are most of the board will be unused throughout the course of a game. For this reason, I want to begin with the board being 16x16 and add new `Squares` as the board is scrolled.

As mentioned in Basic Classes, I will use two variables to keep track of the position of the board: `int[] bounds` and `int[] origin`. These will keep track of the position of the edges of the board and the coordinates of [0,0], respectively.

`bounds` is used to solve the earlier problem with efficient use of memory. This is done by using an algorithm similar to the one below:

```
public void BoardScrollUp() {
    //check if the square in the top left position on the visible board has the
same Y coordinate as the currently stored boundary for the top of the board
    if square at (0,0) has Y coordinate equal to upper Y bound {
        //if it does, that means we are at the edge of the board and need to make
a new row of squares
        for (int i = left X bound; i < right X bound; i++) {
           add a new square at [current X, upper Y bound + 1]
        }
    }
}
```

`origin` simply stores the coordinates of [0,0], and using this I will be able to calculate which squares should be showing on the screen at any time.

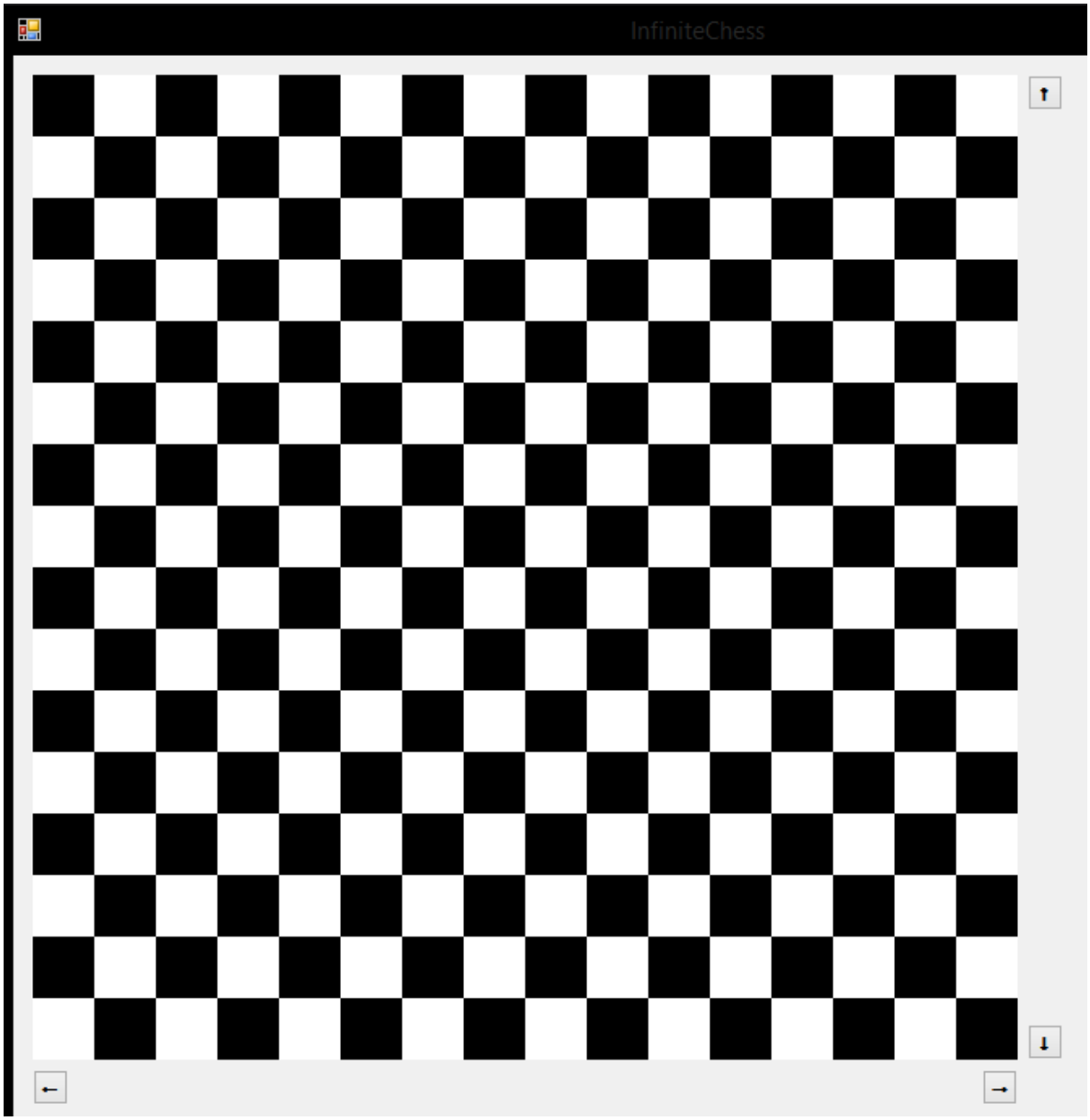
I will now add these two variables to my list of global variables, and while I'm there I will also create a `size` variable to store the size of the visible section of the board, so that this doesn't become hard-coded into the game. Doing this also means I can have the boundaries be initialised to match the size of the visible board: if the initial size is 16x16 then the upper Y boundary would be 15, but if the initial size was 10x10, the upper Y boundary would need to be 9. I will add the code to do this automatically in the constructor for the form itself.

```
//global variables
public static List<Square> board = new List<Square>(); //stores all squares of the board
public static int[] origin = { 0, 570 }; //coordinates of [0,0]
public static int[] bounds = { 0, 0, 0, 0 }; //boundaries of the generated board
public static int[] size = { 16, 16 }; //size of the visible board

public InfinteChess()
{
    InitializeComponent();
    bounds[1] = (size[0] - 1); bounds[3] = (size[1] - 1); //initialises the boundaries
}
```

Now that I have a way to keep track of a larger board, I can add scrolling functionality. While scroll bars are an option in Windows Forms, because the board has a dynamic (and large) size, these will not be a suitable option. The position of the bar would change each time the board increases in size, and when the board becomes very large even the smallest scroll would move many squares, making it difficult to scroll the board precisely where the user wants.

Instead, I will use buttons that can be clicked to scroll in a certain direction. These buttons will be called `sUp`, `sDown`, `sRight` and `sLeft`, and each will feature a text arrow

indicating the direction the button will scroll the board. After adding them to the window, the game looks like this:



The code for each button will be largely similar, so I will test the system with the scroll up button (`sUp`) first, and then copy and adapt the code for each of the other buttons. For this, I will use another debug label which will output the current value of `bounds`.

Using the algorithm from above, I have written the following code:

```
private void sUp_Click(object sender, EventArgs e)
{
    Square edge = GameContainer.findSquareByCoords(0, 0);
    if (edge.indexY == bounds[3]) {
        bounds[3]++;
        for (int j = bounds[0]; j <= bounds[1]; j++) {
            board.Add(new Square { X = origin[0] + 38 * j,
                                   Y = origin[1] - bounds[3] * 38,
                                   indexX = (short)j,
                                   indexY = (short)bounds[3] });
        }
    }
    debug3.Text = $"{bounds[0]},{bounds[1]},{bounds[2]},{bounds[3]}";
}
```

After running the program, the label initially displays `0,15,0,15`, which is the expected value. After pressing the scroll up button, this changes to `0,15,0,16`, which is also what I'd expect, since the board starts as 16x16 and I am trying to scroll up. However, this function is not quite complete; while pressing scroll will update boundaries and generate new squares if necessary, the squares that are currently visible do not change. For example, before pressing this button, the square in the bottom left corner was [0,0]. After scrolling up, I would expect this to become [0,1], which does not happen (it stays as [0,0]). This is because I need to update each `Square` in `board` so that they have the new correct coordinates. I will create a new function, `updateSquares` to update the coordinates of each `Square` when the board is scrolled, and then call this in `sUp_Click`:

```
private void sUp_Click(object sender, EventArgs e)
{
    Square edge = GameContainer.findSquareByCoords(0, 0);
    updateSquares(1, false, sender);
    if (edge.indexY == bounds[3]) {
        bounds[3]++;
        for (int j = bounds[0]; j <= bounds[1]; j++) {
            board.Add(new Square { X = origin[0] + 38 * j,
                                   Y = origin[1] - bounds[3] * 38,
                                   indexX = (short)j,
                                   indexY = (short)bounds[3] });
        }
    }
    debug3.Text = $"{bounds[0]},{bounds[1]},{bounds[2]},{bounds[3]}";
}

public void updateSquares(int amount, bool isX, object sender)
{
    origin[isX ? 0 : 1] += 38 * amount;
    if (isX) { foreach (Square s in board) { s.X += 38 * amount; } }
    else { foreach (Square s in board) { s.Y += 38 * amount; } }
}
```

This modified code gives the expected result; here is table which shows the values of each debug label when `sUp` is pressed a given number of times:

NUMBER OF PRESSES	TOP-RIGHT SQUARE	BOUNDS
0	[15,15]	0,15,0,15
1	[15,16]	0,15,0,16
2	[15,17]	0,15,0,17
3	[15,18]	0,15,0,18

Given that this code works, I can now copy and adapt it for the other 3 buttons to give scrolling functionality in each direction.

```
private void sDown_Click(object sender, EventArgs e)
{
    Square edge = GameContainer.findSquareByCoords((size[0] - 1) * 38 + 1, (size[1] - 1) * 38 + 1);
    updateSquares(-1, false, sender);
    if (edge.indexY == bounds[2]) {
        bounds[2]--;
        for (int j = bounds[0]; j <= bounds[1]; j++) {
            board.Add(new Square { X = origin[0] + 38 * j,
                                   Y = origin[1] - bounds[2] * 38,
                                   indexX = (short)j,
                                   indexY = (short)bounds[2] });
        }
    }
    debug3.Text = $"{bounds[0]},{bounds[1]},{bounds[2]},{bounds[3]}";
}

private void sRight_Click(object sender, EventArgs e)
{
    Square edge = GameContainer.findSquareByCoords((size[0] - 1) * 38 + 1, (size[1] - 1) * 38 + 1);
    updateSquares(-1, true, sender);
    if (edge.indexX == bounds[1]) {
        bounds[1]++;
        for (int j = bounds[2]; j <= bounds[3]; j++) {
            board.Add(new Square { X = origin[0] + bounds[1] * 38,
                                   Y = origin[1] - 38 * j,
                                   indexX = (short)bounds[1],
                                   indexY = (short)j });
        }
    }
    debug3.Text = $"{bounds[0]},{bounds[1]},{bounds[2]},{bounds[3]}";
}

private void sLeft_Click(object sender, EventArgs e)
{
    Square edge = GameContainer.findSquareByCoords(0, 0);
    updateSquares(1, true, sender);
    if (edge.indexX == bounds[0]) {
        bounds[0]--;
        for (int j = bounds[2]; j <= bounds[3]; j++) {
            board.Add(new Square { X = origin[0] + bounds[0] * 38,
                                   Y = origin[1] - 38 * j,
                                   indexX = (short)bounds[0],
                                   indexY = (short)j });
        }
    }
    debug3.Text = $"{bounds[0]},{bounds[1]},{bounds[2]},{bounds[3]}";
}
```

The main difference between these functions are the elements of `bounds` that are being used and modified. Other than that, they are all fairly similar. Since scrolling is now implemented in all directions, I can comprehensively test the scrolling functionality. To do this, I will define a sequence of buttons to press, the expected outcome of this, and then the actual outcome:

- **SEQUENCE** refers to the sequence of buttons that was pressed. *xA* represents *x* scrolls in the direction *A*, where *x* is a positive integer and *A* is a directional arrow. For example, 2↑ means scroll upwards twice, and 3→,1↓ means scroll to the right 3 times and downwards once.
- **EX. ORIGIN** refers to the expected index of the `Square` at (0,0) after the sequence has been executed. This will be in the form [*x*,*y*], where *x* and *y* are integers representing the index of this `Square`.
- **EX. BOUNDS** refers to the expected value of `bounds` after the sequence has been executed. This will be in the form *w*,*x*,*y*,*z*, where *w*, *x*, *y* and *z* are integers representing the lower x, upper x, lower y and upper y boundaries of the board, respectively.
- **ACT. ORIGIN** refers to the actual index of the `Square` at (0,0). This has the same form as ORGN_E and will be a screenshot of the debug label.
- **ACT. BOUNDS** refers to the actual value of `bounds`. This has the same form as BNDS_E and will be a screenshot of the debug label.
- The initial index of the `Square` at (0,0) is [0,15]. The initial value of `bounds` is 0,15,0,15.

SEQUENCE	EX. ORIGIN	EX. BOUNDS	ACT. ORIGIN	ACT. BOUNDS
1↑	[0,16]	0,15,0,16	0, 16,	0,15,0,16
1↓	[0,14]	0,15,-1,15	0, 14	0,15,-1,15
1→	[1,15]	0,16,0,15	1, 15,	0,16,0,15
1←	[-1,15]	-1,15,0,15	-1, 15	-1,15,0,15
2←	[-2,15]	-2,15,0,15	-2, 15,	-2,15,0,15
5↓	[0,10]	0,15,-5,15	0, 10	0,15,-5,15
1↑,1→	[1,16]	0,16,0,16	1, 16,	0,16,0,16
1↑,1←,2→,2↓	[1,14]	-1,16,-1,16	1, 14	-1,16,-1,16
3↓,1→,5↑	[1,17]	0,16,-3,17	1, 17	0,16,-3,17
4→,4↓	[4,11]	0,19,-4,15	4, 11,	0,19,-4,15
8←,1↓	[-8,14]	-8,15,-1,15	-8, 14,	-8,15,-1,15
4→,6↑,8←	[-4,21]	-4,19,0,21	-4, 21,	-4,19,0,21

All the results match up with the expected values, which means board scrolling works and is finished.

The Piece Class

The next thing to implement is the `Piece` class, which represents the framework for pieces in the game and their properties. This class is outlined in the basic class section already, so implementing a basic framework is simple enough. I will create this in a new file, `Pieces.cs`, to keep it better organised.

```
namespace InfiniteChess
{
    public enum PieceType { PAWN, KNIGHT, ROOK, BISHOP, QUEEN, KING, MANN, HAWK, CHANCELLOR, NONE };
    public enum PieceColour { BLACK, WHITE }; //WHITE moves up the board, BLACK down

    public class Piece
    {
        public PieceType type { get; private set; }
        public Square square { get; private set; }
        public Bitmap icon { get; private set; }
        public PieceColour colour { get; private set; }

        public Piece(PieceType t, Square s, PieceColour c) {

        }
    }
}
```

The constructor for `Piece` will require initialisation of `icon`, which is the graphic that piece will use. I will need to create or find some graphics for each piece so that I can start using pieces.

For now, I have made some basic images which are just a letter to represent each piece. To the right can be seen a black hawk, black queen, white pawn and white bishop. I created a new folder called `images` which is itself in `res`. This then two folders, `black` and `white`, which contain the graphics for each piece in that colour.

I can now fill in the constructor so that I can start using pieces:

```
public Piece(PieceType t, Square s, PieceColour c) {
    type = t; colour = c; square = s;
    icon = new Bitmap($"res/image/{c.ToString()}/{t.ToString()}.png");
}
```

I will now add a new attribute to `InfiniteChess`, which will be `List<Piece> pieces`, as mentioned in basic classes. I will use this list to hold all the pieces that are currently in the game. I am using a list rather than an array because the number of pieces could change throughout the course of the game (arrays need a defined size on initialisation).

```
public static List<Piece> pieces = new List<Piece>();
```

To test this class, I will need to draw some pieces to the board. To do this, I will first create a method which will initialise a list of pieces with 1 of each type of piece in each colour. This method will be in the `Piece` class itself.

```
public static List<Piece> IntializePieces()
{
    List<Piece> pieces = new List<Piece>();
    for (int i = 0; i < 2; i++) {
        var w = i == 0 ? PieceColour.WHITE : PieceColour.BLACK;
        pieces.AddRange(new List<Piece> {
        new Piece(PieceType.PAWN, GameContainer.findSquareByIndex(3, 4 + i), w),
        new Piece(PieceType.KNIGHT, GameContainer.findSquareByIndex(4, 4 + i), w),
        new Piece(PieceType.ROOK, GameContainer.findSquareByIndex(5, 4 + i), w),
        new Piece(PieceType.BISHOP, GameContainer.findSquareByIndex(6, 4 + i), w),
        new Piece(PieceType.QUEEN, GameContainer.findSquareByIndex(7, 4 + i), w),
        new Piece(PieceType.KING, GameContainer.findSquareByIndex(8, 4 + i), w),
        new Piece(PieceType.HAWK, GameContainer.findSquareByIndex(9, 4 + i), w),
        new Piece(PieceType.CHANCELLOR, GameContainer.findSquareByIndex(10, 4 + i), w),
        new Piece(PieceType.MANN, GameContainer.findSquareByIndex(11, 4 + i), w),
        new Piece(PieceType.NONE, GameContainer.findSquareByIndex(12, 4 + i), w) });
    }
    return pieces;
}
```

I can call this method when the game starts and set the value of `pieces` equal to the value this function returns. Later, I could move this list a configuration file rather than being hard coded into the program, but for testing purposes this will suffice. The final thing that has to be done to use these is to actually draw them.

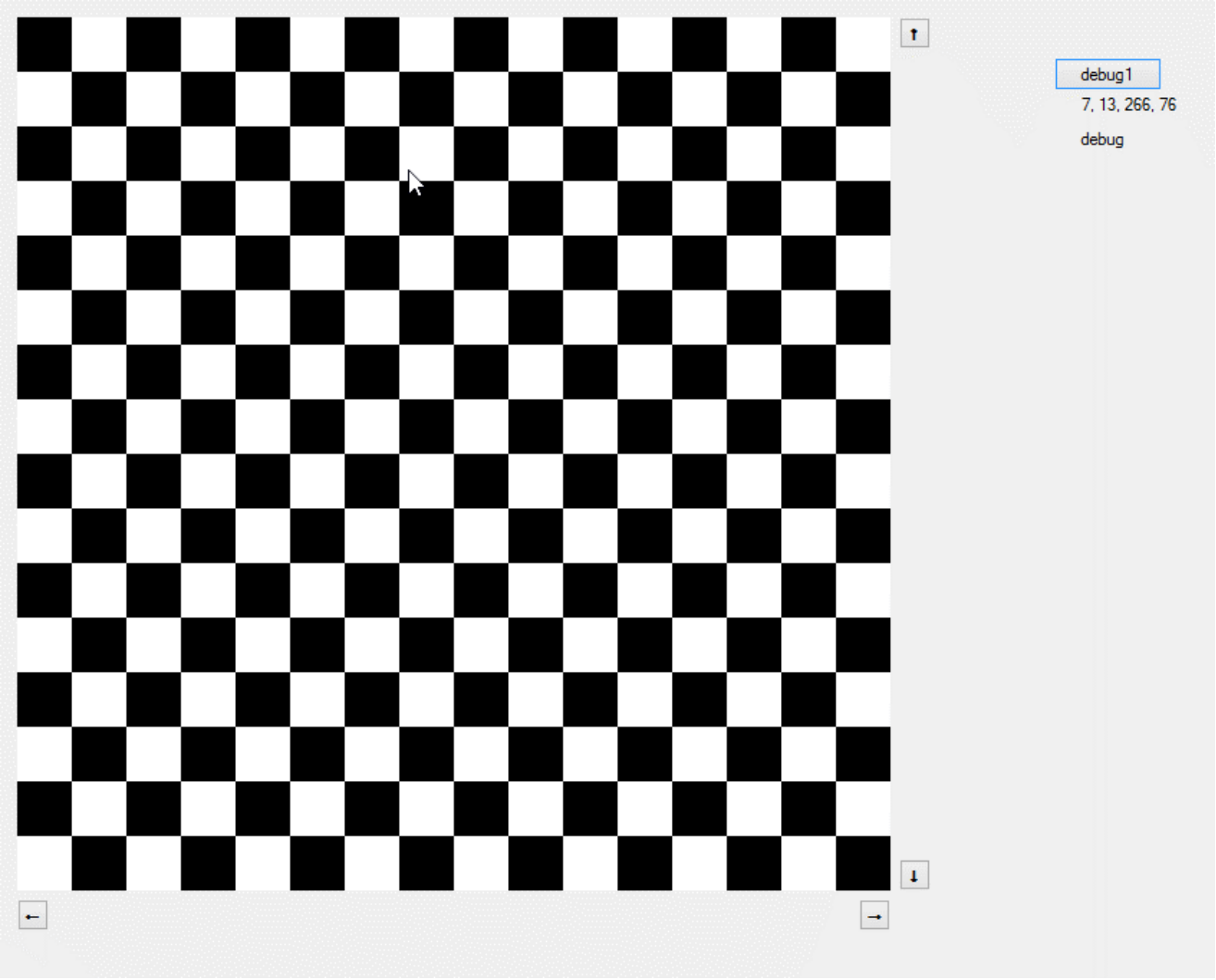
The current function to draw the board is `InitialiseBoard()`, which both draws the board background image and creates the list of squares which represents the board. There is no concept of layers in the graphics here, so if I want to move something on-screen, I have to redraw everything. This means it is necessary to call a function that redraws the board and pieces every time something needs to move. `InitialiseBoard()` is not currently suitable for this because it also initialises the list of squares, which is not something I want to happen each time a piece moves. For this reason, I will split up this function into an initialisation section and a drawing section:

```
//create the logical board
public void InitialiseBoard() {
    for (int i = 0; i < 16; i++) { //columns
        for (int j = 0; j < 16; j++) { //rows
            board.Add(new Square {
                X = origin[0] + 38 * i,
                Y = origin[1] - 38 * j,
                indexX = (short)i,
                indexY = (short)j });
            //g.DrawRectangle( new Pen(Color.Green), origin[0] + 38 * i, origin[1] - 38 * j, 38, 38);
        }
    }
    drawBoard();

}

public void drawBoard() {
    Graphics g = boardPanel.CreateGraphics();
    g.DrawImage(new Bitmap(new Bitmap("res/image/board.png"), new Size(608, 608)), 0, 0);
    g.Dispose();
}
```

Now I have a clear distinction between the function to call for initialisation and the function to call for redrawing. All I need to do now is insert some code to draw each piece in `pieces` into `drawBoard()`.

```
public void drawBoard() {
    Graphics g = boardPanel.CreateGraphics();
    g.DrawImage(new Bitmap(new Bitmap("res/image/board.png"), new Size(608, 608)), 0, 0);
    foreach (Piece p in pieces) {
        Bitmap b = new Bitmap(p.icon, new Size(38, 38));
        g.DrawImage(b, p.square.X, p.square.Y);
    }
    g.Dispose();
}
```

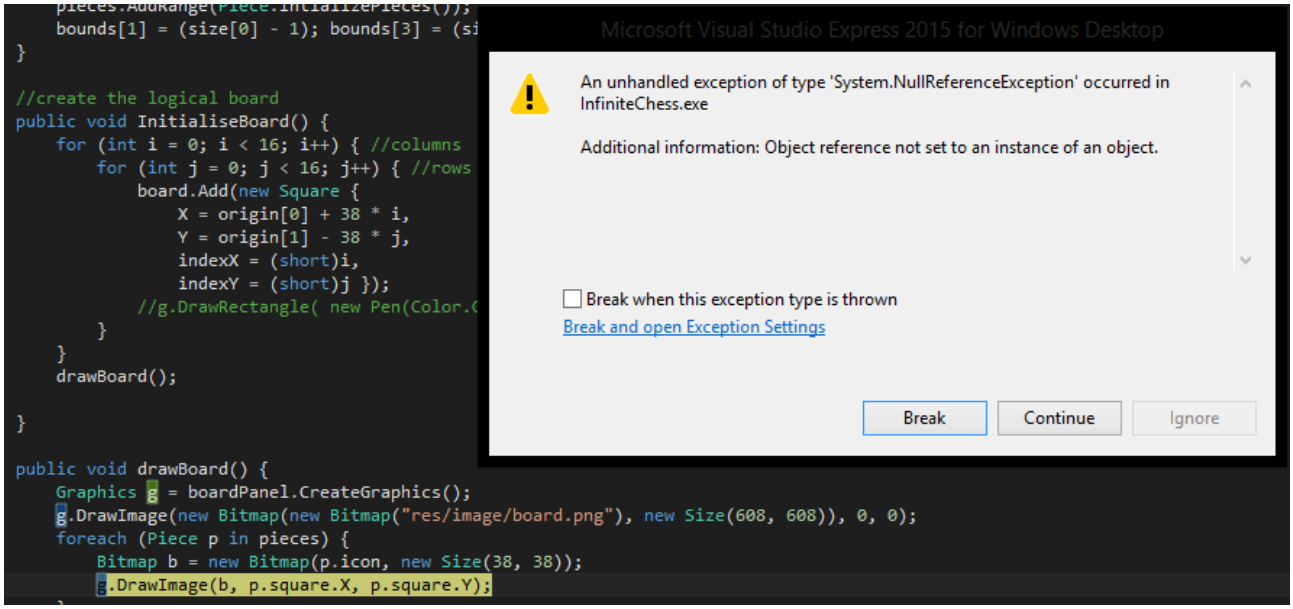
Running the program:



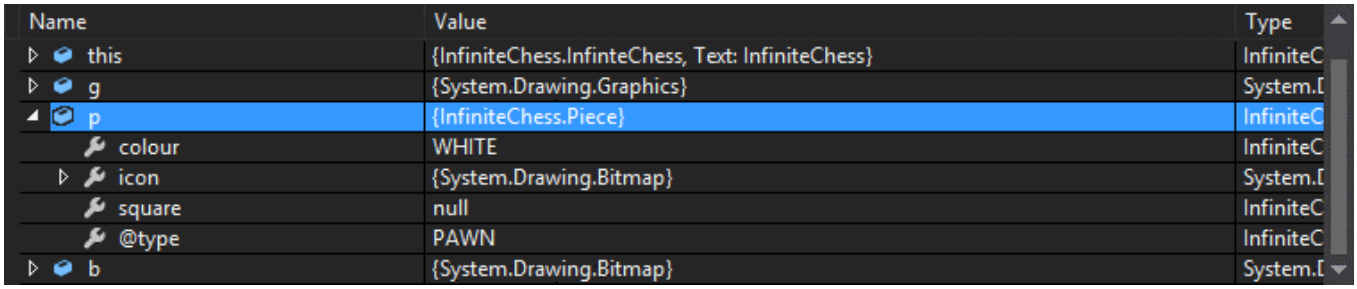
Nothing happens. The reason for this is that even though I created a function which will initialise a `List<Piece>` with some testing pieces, I did not set the actual `pieces` variable to be equal to this. I add this to the initialise function and try again:

```
public InfinteChess()
{
    InitializeComponent();
    pieces.AddRange(Piece.IntializePieces());
    bounds[1] = (size[0] - 1); bounds[3] = (size[1] - 1); //initialises the boundaries
}
```

But this happens:



A null reference exception occurs. The line where the exception occurred is that in which the piece is drawn, which means that one of the arguments passed into the function `DrawImage` must have been null. Visual Studio has a helpful feature which allows me to see the values of variables at the moment an exception is thrown. The list looks like this:



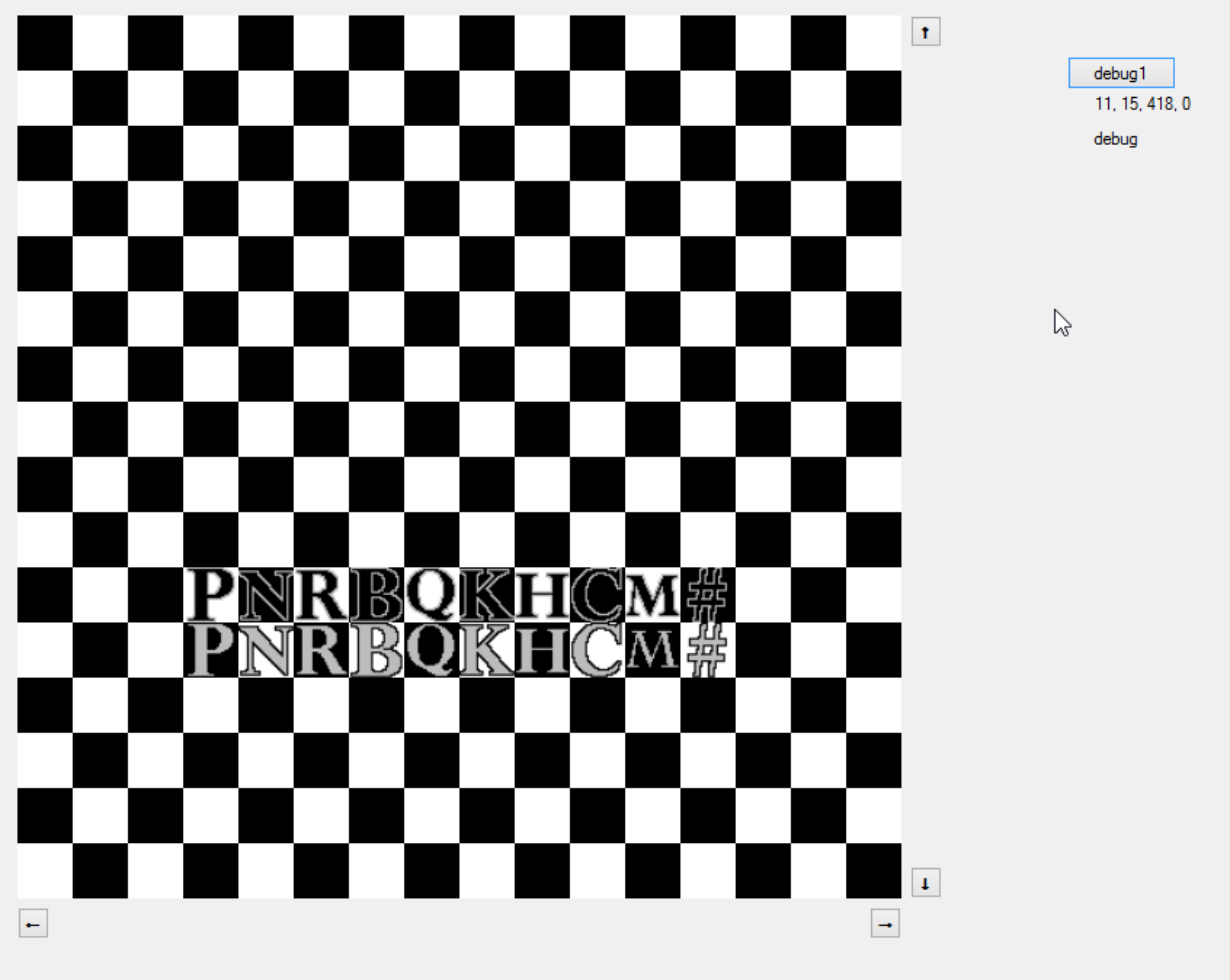
`p` is the current piece in the loop (`foreach(Piece p in pieces)`) that is going to be drawn. Looking at the attributed of `p`, we can see that `square` has the value `null`. This means that when the `Square` associated with the piece was created, one of its attributes was also `null`. Looking at the piece initialisation function again (see above), the function used to attach pieces to squares is `GameContainer.findSquareByIndex`. If we take a look at the code for this function:

```
public static Square findSquareByIndex(int indexX, int indexY) {
    foreach (Square s in InfinteChess.board) {
        if (indexX == s.indexX && indexY == s.indexY) return s; }
    return null;
}
```

This only returns null if it couldn't match any of the squares in `board`. I decide to check the initialisation function for the game and I realise that the board is only being initialised after I press the button, but `pieces` is being initialised when the program loads. This means that every piece is being created with null squares, because there are no squares when the pieces are created. This is a simple fix, all I have to do is call `InitialiseBoard()` before `pieces` is initialised.

```
public InfinteChess()
{
    InitializeComponent();
    InitialiseBoard();
    pieces.AddRange(Piece.IntializePieces());
    bounds[1] = (size[0] - 1); bounds[3] = (size[1] - 1);
}
```

This now works as intended; some pieces have been drawn to the screen:



They don't look quite right though, having them the same size as the squares of the board doesn't look good. Changing their size to 32x32 looks like a more reasonable size, but they are now in the top left corner of each square, which is not what I want. Adding 3 to both the X and Y coordinates of each image fixes this issue, and their current appearance can be seen on the right.

While I was fixing the piece images, I noticed I use the value 38 (the size of the squares of the board) a lot in the code. I might want to change this value at a later point (perhaps for different resolutions), so I think it's a good idea now to create a variable which has the value of 38 and replace all instances of the number with the variable. I will call this variable `sf` for scale factor.

Calculating Piece Movement

Having pieces is no good if they can't move. Making them move is trivial but calculating where they can legally move will be more difficult.

There are two categories of pieces when it comes to how their movement is defined: static movement and linear movement. Which piece is which is defined in the table on the left. Static means that the squares that the piece can move to are finite and defined relative to the position of the piece. For example, a king can move one square in any direction, meaning it has a maximum of 8 possible moves at any time. Linear on the other hand means that the piece's movement is defined by a line or lines and can move in any number of squares in that line(s). In regular chess, this would still mean they have a finite number of moves, since there are only a finite number of squares and the line of movement would hit the edge of the board quite soon. In infinite chess however, there is no edge; the line of movement will carry on indefinitely, and therefore so will the choice of moves. This means that the two categories will have to have their movement defined differently in terms of the code involved.

STATIC	LINEAR
Pawn	Bishop
Mann	Rook
Knight	Chancellor
Hawk	Queen
King	

`calculateMovement` will be a function of the `Piece` class and take no arguments since it will calculate the movement of the instance of `Piece` that called it. The function will return a `List<Square>` which will represent the valid moves relative to the `Square` of the piece.

```
public List<Square> calculateMovement() {
    List<Square> moves = Square.emptyList();
    switch (type) {
        case (PieceType.PAWN):
        case (PieceType.MANN):
        case (PieceType.KNIGHT):
        case (PieceType.HAWK):
        default:
            return moves;
    }
}
```

I will start with the easier of the two (static pieces). The function will start with the framework seen on the right.

The pawn is the simplest piece; most of the time it just moves forward one Square (exceptions such as capturing, the first movement rule and en-passant can be added later).

```
case (PieceType.PAWN): {
        var direction = colour == PieceColour.WHITE ? square.indexY + 1 : square.indexY - 1;
        Square attempt = GameContainer.findSquareByIndex(square.indexX, direction);
        moves.Add(attempt);
        foreach (Piece p in Chess.pieces) { if (p.square == attempt) moves.Remove(attempt); }
        return moves;
    }
```

The pawn is the only piece which has movement that depends on which colour it is, so I set up a variable to decide which direction movement should go. I then use `attempt` to represent the `Square` in front of the pawn in that direction and add it to the list. I then check if any other piece is on that `Square`, and if so, remove it from the list. This function will therefore output either one square in front of the pawn or no squares at all.

To test this, I could output the value of moves to one of the debug labels, but for other pieces it would become tedious to verify if the returned list is correct. An easier way would be to draw something on the squares returned so that I can visually see if it's working. This is something that will need to be done anyway so that the user can see what their valid moves are. I will write a basic function in `GameContainer` which will just draw a red rectangle on every `Square` that is returned, and then attach this to `OnMouseClick` to draw a piece's movement when it is clicked.

```
public void drawMoves(Piece p) {
    Graphics g = CreateGraphics();
    foreach (Square s in p.calculateMovement()) {
        g.DrawRectangle(
            new Pen(Color.FromArgb(106, 255, 0 ,0)),
            s.X, s.Y,
            Chess.sf, Chess.sf);
    }
    g.Dispose();
}
```

```
protected override void OnMouseClick(MouseEventArgs e)
{
    Square cursorSquare = findSquareByCoords(e.X, e.Y);
    foreach (Piece p in Chess.pieces) {
        if (p.square == cursorSquare) drawMoves(p);
    }
}
```

Running this code and clicking on either pawn does the following:

Nothing drawn. However, since the pawns are in front of each other, this is actually the expected result. It is not possible to tell whether the code is working correctly in this situation, so I will move the rows of pieces apart. Doing this and then trying again:

There is a red square drawn where I expect, but it's a little hard to see, so I will make it thicker by just drawing additional smaller rectangles. After adjusting the constants to get the square centred properly, following is the code used to draw and the result of it:

```
public void drawMoves(Piece p) {
    Graphics g = CreateGraphics();
    foreach (Square s in p.calculateMovement()) {
        g.DrawRectangle(new Pen(Color.FromArgb(255, 255, 0 ,0)), s.X, s.Y, Chess.sf-1, Chess.sf-1);
        g.DrawRectangle(new Pen(Color.FromArgb(255, 255, 0, 0)), s.X+1, s.Y+1, Chess.sf-3, Chess.sf-3);
        g.DrawRectangle(new Pen(Color.FromArgb(255, 255, 0, 0)), s.X+2, s.Y+2, Chess.sf-5, Chess.sf-5);
    }
    g.Dispose();
```

This result indicates that the code written so far is functioning correctly.

The next piece is the knight. This piece moves two squares in any orthogonal direction, and then an additional square in a direction perpendicular to the original movement (i.e. an L-shape). The best way to implement this movement will be to use an array to represent the movement, with each element being the offset in terms of squares for one possible move with respect to the origin (the square the piece is starting on). I will then iterate through each of these entries and check if there is a piece in any already. Any which are empty will be added to the list that will be returned.

```
case (PieceType.KNIGHT): {
        int[][] attempts = {
            new int[] {-2,1}, new int[] {-1,2},
            new int[] {2,1}, new int[] {1,2},
            new int[] {2,-1}, new int[] {1,-2},
            new int[] {-1,-2}, new int[] {-2,-1} };
        for (int i = 0; i < attempts.Length; i++) {
            Square s = GameContainer.findSquareByIndex(
                square.indexX + attempts[i][0],
                square.indexY + attempts[i][1]);
            bool valid = true;
            foreach (Piece p in Chess.pieces) {
                if (p.square == s) { valid = false; }
            }
            if (valid) { moves.Add(s); }
        }
        return moves;
    }
```

This is not too different from the code for the pawn. The result of clicking the black knight can be seen on the left, which is the expected result; 6 of the 8 possible squares are free, while the other 2 are blocked by a white pawn and white rook.

The next piece is the king, which also shares its movement with the mann. Even though the king has a special status among pieces, right now I am only concerned with the movement, so there should be no issues with using the exact same code for both.

For these two pieces, I can simply copy the code for the knight, but with the numbers in the array adjusted:

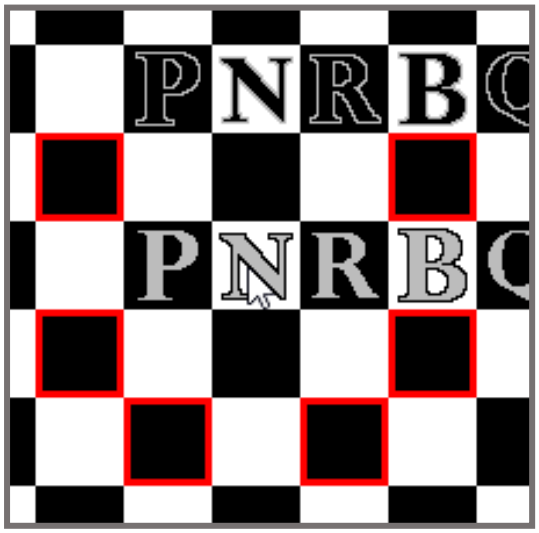
```
case (PieceType.KING): {
        int[][] attempts = {
            new int[] {-1,-1}, new int[] {-1,0},
            new int[] {-1,1}, new int[] {0,-1},
            new int[] {0,1}, new int[] {1,-1},
            new int[] {1,0}, new int[] {1,1} };
        for (int i = 0; i < attempts.Length; i++)
        {
            Square s = GameContainer.findSquareByIndex(
                square.indexX + attempts[i][0],
                square.indexY + attempts[i][1]);
            bool valid = true;
            foreach (Piece p in Chess.pieces)
            {
                if (p.square == s) { valid = false; }
            }
            if (valid) { moves.Add(s); }
        }
        return moves;
    }
case (PieceType.MANN): { goto case PieceType.KING; }
```

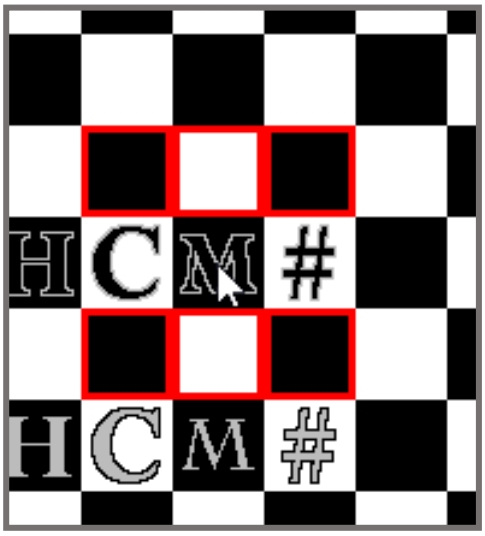
The final static piece is the hawk. This piece moves either 2 or 3 squares in any direction and can jump over pieces in the way. This means the code would once again be exactly the same, but with a modified array. Having all this repeated code seems rather redundant, so I decide to try and have each of these pieces direct to the same function. The most readable way to do this is to store the arrays used previously in text files as numbers that can be read and interpreted in the same way. The file for the king can be seen to the right; as you can see it contains all the same numbers as the array did, but it makes it much easier to deal with and the array is no longer hardcoded into the game. The modified code with the file read operation can be seen below.

```
-1,1
-1,0
-1,-1
0,1
0,-1
1,1
1,0
1,-1
```

```
case (PieceType.KING): {
        string[] attempts = File.ReadAllLines($"res/movement/{type.ToString()}.txt");
        foreach (string att in attempts)
        {
            Square s = GameContainer.findSquareByIndex(
                square.indexX + Int32.Parse(att.Split(',')[0]),
                square.indexY + Int32.Parse(att.Split(',')[1]));
            bool valid = true;
            foreach (Piece p in Chess.pieces) {
                if (p.square == s) { valid = false; }
            }
            if (valid) moves.Add(s);
        }
        return moves;
    }
case (PieceType.MANN): { goto case PieceType.KING; }
case (PieceType.KNIGHT): { goto case PieceType.KING; }
case (PieceType.HAWK): { goto case PieceType.KING; }
```

And the results of clicking these pieces:





These appear to be functioning as expected. By moving pieces out from the rows, I can verify each of the possible moves is being checked as intended. This means the movement calculation for static pieces is complete.

Now for the linear pieces. As mentioned earlier, I will have to use a different approach for these pieces, because they don't have a set of predefined squares they can move to. As well as this, they cannot jump over pieces like the hawk, so they must account for other pieces stopping a line of movement at any point.

The algorithm for these kind of pieces is going to be something like the following:

```
case Bishop: {
  create empty list of squares
  int max = largest distance from the piece to the edge of visible board
  for (int i = 1; i <= j; i++) {
    Square attempt = findSquare(this.indexX – i, this.indexY – i)
    if there's a piece on the square, break out of the loop
    add attempt to list
  }
  for (int i = 1; i <= j; i++) {
    Square attempt = findSquare(this.indexX – i, this.indexY + i)
    if there's a piece on the square, break out of the loop
    add attempt to list
  }
  //2 more loops for the other 2 directions
  return list
}
```

There is a built-in function to find the largest of two integers, but I need to find the largest of four in this case. I may need to do this again at another point in development, so I will write a function that will take an array of integers and return the largest one.

```
public int findLargest(int[] i) {
    int j = int.MinValue;
    foreach (int k in i) { if (k > j) j = k; }
    return j;
}
```

The initial iteration of this code looks like this:

```
case (PieceType.BISHOP): {
        int max = Chess.findLargest(new int[] {
            square.indexX-Chess.bounds[0],
            square.indexY-Chess.bounds[2],
            Chess.bounds[1]-square.indexX,
            Chess.bounds[3]-square.indexY} );
        for (int i = 1; i <= max; i++) {
            Square attempt = GameContainer.findSquareByIndex(square.indexX - i, square.indexY - i);
            foreach (Piece p in Chess.pieces) { if (p.square == attempt) break; }
            moves.Add(attempt);
        }
        for (int i = 1; i <= max; i++) {
            Square attempt = GameContainer.findSquareByIndex(square.indexX + i, square.indexY - i);
            foreach (Piece p in Chess.pieces) { if (p.square == attempt) break; }
            moves.Add(attempt);
        }
        for (int i = 1; i <= max; i++) {
            Square attempt = GameContainer.findSquareByIndex(square.indexX - i, square.indexY + i);
            foreach (Piece p in Chess.pieces) { if (p.square == attempt) break; }
            moves.Add(attempt);
        }
        for (int i = 1; i <= max; i++) {
            Square attempt = GameContainer.findSquareByIndex(square.indexX + i, square.indexY + i);
            foreach (Piece p in Chess.pieces) { if (p.square == attempt) break; }
            moves.Add(attempt);
        }
        return moves;
    }
```

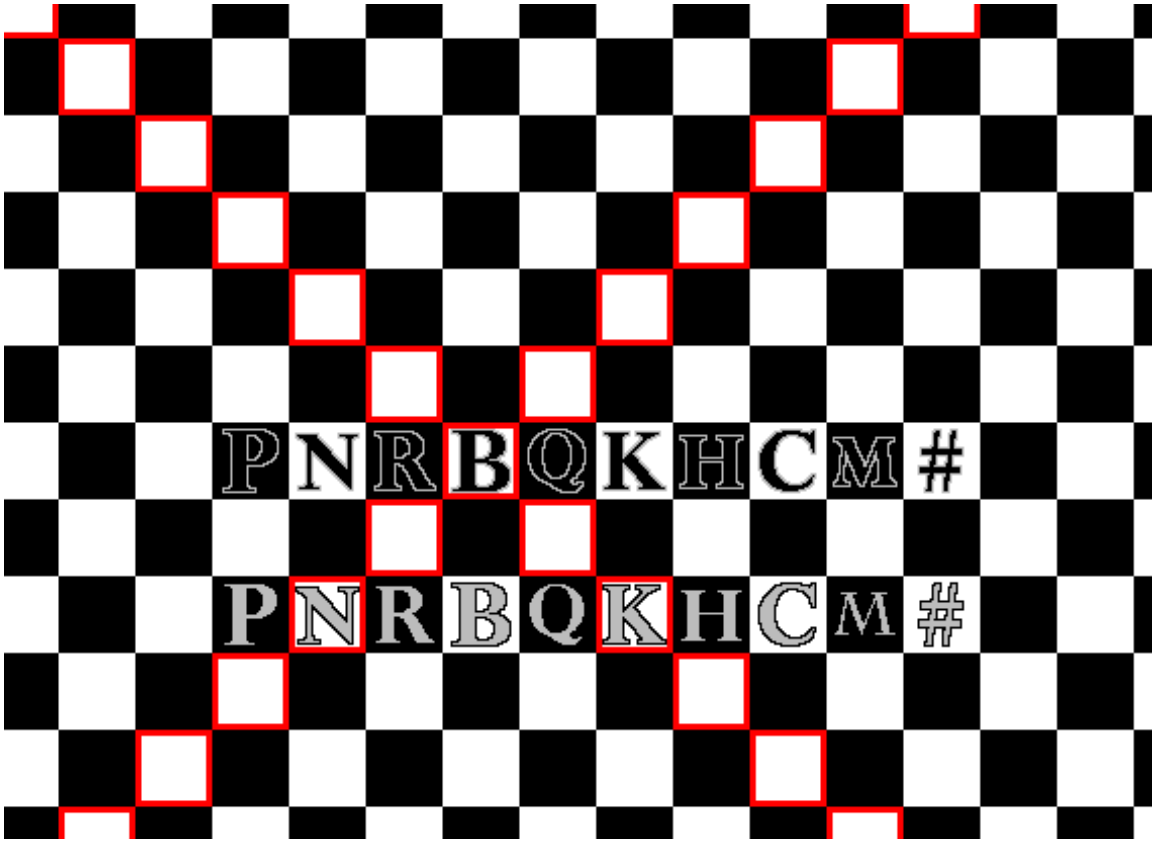
However, this throws a `NullReferenceException` when a bishop is clicked. The limit I am using for each for loop is the largest of the 4 distances from the piece to the edges of the board. However, this means that in some direction the program is attempting to check past the edge of the visible board if it's not stopped by another piece being in the way, which in a lot of cases will lead it to check squares which don't exist, and `findSquareByIndex` will return `null` in these cases. This means that `drawMovement` throws an exception (cannot draw a null square).

To fix this, I need to break out of the loop if `attempt` becomes equal to `null`. The standard approach to this would be to just add an `if` statement with a `break` statement in each loop, but this code is already a bit messy, and that would make it worse. A more clever and much shorter way to fix this is to use a null-conditional operator in the following way:

```
Square attempt = GameContainer.findSquareByIndex(square.indexX - i, square.indexY
- i) ?? square;
```

The program will check for the next `Square` in the line as usual, but if the function returns `null`, instead of setting `attempt` to be `null`, it instead sets it to whatever is to the right of `??` (the null-conditional operator), which in this case is `square`. `square` refers to the square of the piece which called this function (i.e. the square the bishop is on), and therefore necessarily will have a piece on it. This means that in the `foreach` loop, this square will be caught, and the `break` statement will be reached, ending the loop for that line.

This is the result of clicking a bishop with the new adjustments:



The program hasn't crashed, which is good, but it is clearly not playing by the rules here. The bishop calculations are ignoring pieces that are in the way. The reason for this is a simple oversight I made; `break` only takes execution out of one loop, and not more. This means that in my code, the `break` statements are jumping out of the `foreach` loop, but then not out the enclosing `for` loop, so the move is getting added to the list anyway.

The best way to fix this is to have a `bool` defined at the start of the entire `case` which is set to true initially, and then becomes false when a piece is found within a `foreach`. There is then an `if` statement after the `foreach` which will add the move if the `bool` is true, and `break` if false. Looking at the code for this class in general, I have used this same structure (foreach) many times with no changes at all. I think it would be useful here to move this to another function which will return either true if there is a piece on the square, or false otherwise to reduce the clutter of this class. This can be seen on the right.

```
public static bool checkSquareForPiece(Square s) {
    foreach (Piece p in pieces) {
        if (p.square == s) return true;
    }
    return false;
}
```

This new iteration looks like this:

```
case (PieceType.BISHOP): {
        int max = Chess.findLargest(new int[] {
            square.indexX-Chess.bounds[0],
            square.indexY-Chess.bounds[2],
            Chess.bounds[1]-square.indexX,
            Chess.bounds[3]-square.indexY} );
        for (int i = 1; i <= max; i++) {
            Square attempt = GameContainer.findSquareByIndex(square.indexX - i, square.indexY - i) ?? square;
            if (Chess.checkSquareForPiece(attempt)) break;
            moves.Add(attempt);
        }
        for (int i = 1; i <= max; i++) {
            Square attempt = GameContainer.findSquareByIndex(square.indexX + i, square.indexY - i) ?? square;
            if (Chess.checkSquareForPiece(attempt)) break;
            moves.Add(attempt);
        }
        for (int i = 1; i <= max; i++) {
            Square attempt = GameContainer.findSquareByIndex(square.indexX - i, square.indexY + i) ?? square;
            if (Chess.checkSquareForPiece(attempt)) break;
            moves.Add(attempt);
        }
        for (int i = 1; i <= max; i++) {
            Square attempt = GameContainer.findSquareByIndex(square.indexX + i, square.indexY + i) ?? square;
            if (Chess.checkSquareForPiece(attempt)) break;
            moves.Add(attempt);
        }
        return moves;
    }
```

I have also gone back to the previous piece code and replaced any similar foreach loops with a call of `checkSquareForPiece`.

The result of this iteration:

Much better. However, this code can be improved further. Currently I have 4 consecutive `for` loops which all share 2 lines, and the third line only differs in two characters. I think these can be combined into just one loop. If I just copied each three line section into one for loop, they would all stop as soon as one stopped because of the break statement. I need a way to track each three line section and have it not execute if necessary.

To do this, I will use a `bool[]` which contains 4 values, one for each direction. They all initially started as false, and every time a square is checked, the value for that line is set to whatever `checkSquareForPiece` returns. Additionally, each three line segment only executes if the tracker value for that section is false. What this means is that as soon as something stops one of the lines, just that line will stop and the rest will continue, until all four have stopped (i.e. all four values are true).

While this will make the code a bit messy, it will computationally be a lot faster, since I am now only doing the main iteration once instead of four times.

The implementation of this looks like this:

```
case (PieceType.BISHOP): {
        bool[] tracker = { false, false, false, false };
        int max = Chess.findLargest(new int[] {
            square.indexX-Chess.bounds[0],
            square.indexY-Chess.bounds[2],
            Chess.bounds[1]-square.indexX,
            Chess.bounds[3]-square.indexY} );
        for (int i = 1; i <= max; i++) {
            if (!tracker[0]) {
                Square attempt = GameContainer.findSquareByIndex(square.indexX - i, square.indexY - i) ?? square;
                tracker[0] = Chess.checkSquareForPiece(attempt);
                if (!tracker[0]) moves.Add(attempt);
            }
            if (!tracker[1]) {
                Square attempt = GameContainer.findSquareByIndex(square.indexX + i, square.indexY - i) ?? square;
                tracker[1] = Chess.checkSquareForPiece(attempt);
                if (!tracker[1]) moves.Add(attempt);
            }
            if (!tracker[2]) {
                Square attempt = GameContainer.findSquareByIndex(square.indexX - i, square.indexY + i) ?? square;
                tracker[2] = Chess.checkSquareForPiece(attempt);
                if (!tracker[2]) moves.Add(attempt);
            }
            if (!tracker[3]) {
                Square attempt = GameContainer.findSquareByIndex(square.indexX + i, square.indexY + i) ?? square;
                tracker[3] = Chess.checkSquareForPiece(attempt);
                if (!tracker[3]) moves.Add(attempt);
            }

            if (tracker == new bool[] { true, true, true, true }) { break; }
        }
        return moves;
    }
```

This gives the same result as the previous iteration. While I am now calculating the movement 4 times faster, there is still a lot of repeated code in this function. Using another array which will hold information on which direction to check (which coordinates should be subtracted from in `findSquareByIndex`), I can make this even better:

```
case (PieceType.BISHOP): {
        bool[] tracker = { false, false, false, false };
        int[][] direction = { new int[]{-1,-1}, new int[]{-1,1}, new int[]{1,-1}, new int[]{1,1} };

        int max = Chess.findLargest(new int[] {
            square.indexX-Chess.bounds[0], square.indexY-Chess.bounds[2],
            Chess.bounds[1]-square.indexX, Chess.bounds[3]-square.indexY} );

        for (int i = 1; i <= max; i++) {
            for (int j = 0; j < 4; j++) {
                if (!tracker[j]) {
                    Square attempt = GameContainer.findSquareByIndex(
                        square.indexX - i*direction[j][0], square.indexY - i*direction[j][1]) ?? square;
                    tracker[j] = Chess.checkSquareForPiece(attempt);
                    if (!tracker[j]) moves.Add(attempt);
                }
            }
        }
        return moves;
    }
```

This new code is much shorter, and still gives the same result. This will be the final iteration for the bishop.

The rook is pretty much identical to the bishop, except the lines are orthogonal instead of diagonal. This means the code for the bishop can be copied, `direction` can be modified, and it will work:

```
case (PieceType.ROOK): {
        bool[] tracker = { false, false, false, false };
        int[][] direction = { new int[]{-1,0}, new int[]{1,0}, new int[]{0,-1}, new int[]{0,1} };
        int max = Chess.findLargest(new int[] {
            square.indexX-Chess.bounds[0], square.indexY-Chess.bounds[2],
            Chess.bounds[1]-square.indexX, Chess.bounds[3]-square.indexY} );
        for (int i = 1; i <= max; i++) {
            for (int j = 0; j < 4; j++) {
                if (!tracker[j]) {
                    Square attempt = GameContainer.findSquareByIndex(
                        square.indexX - i*direction[j][0], square.indexY - i*direction[j][1]) ?? square;
                    tracker[j] = Chess.checkSquareForPiece(attempt);
                    if (!tracker[j]) moves.Add(attempt);
                }
            }
        }
        return moves;
    }
```

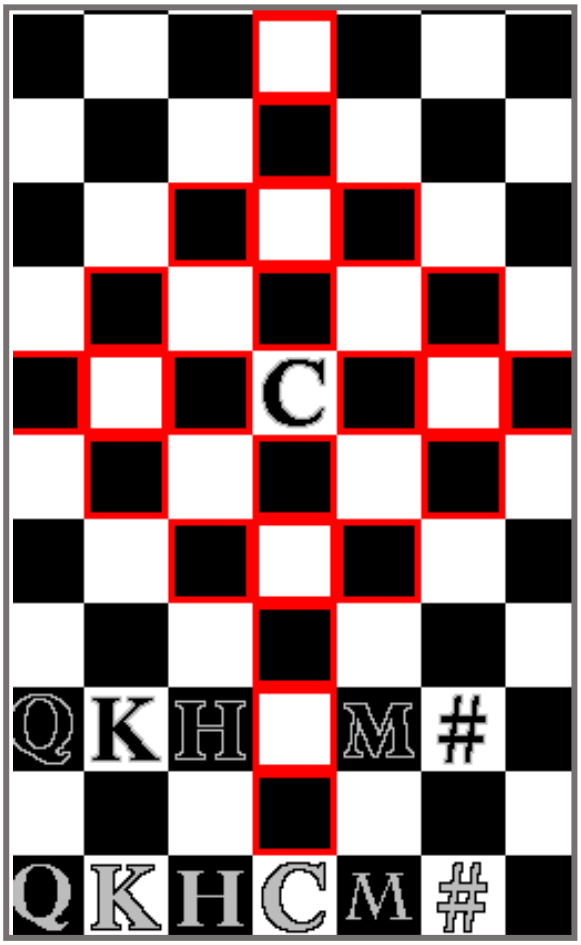
The result of this code can be seen to the right. However, once again, there is a lot of redundant code here. Only one line differs between the code for the bishop and the rook. This means I could easily direct the rook to run the code for the bishop, and just adjust the constants on the fly as necessary. The improved code can be seen below.

```
case (PieceType.ROOK): { goto case PieceType.BISHOP; }
case (PieceType.BISHOP): {
        bool[] tracker = { false, false, false, false };
        int[][] direction = type == PieceType.BISHOP ?
            new int[][] { new int[]{-1,-1}, new int[]{-1,1}, new int[]{1,-1}, new int[]{1,1} } :
            new int[][] { new int[]{-1,0}, new int[]{1,0}, new int[]{0,-1}, new int[]{0,1} };
        int max = Chess.findLargest(new int[] {
            square.indexX-Chess.bounds[0], square.indexY-Chess.bounds[2],
            Chess.bounds[1]-square.indexX, Chess.bounds[3]-square.indexY} );
        for (int i = 1; i <= max; i++) {
            for (int j = 0; j < 4; j++) {
                if (!tracker[j]) {
                    Square attempt = GameContainer.findSquareByIndex(
                        square.indexX - i*direction[j][0], square.indexY - i*direction[j][1]) ?? square;
                    tracker[j] = Chess.checkSquareForPiece(attempt);
                    if (!tracker[j]) moves.Add(attempt);
                }
            }
        }
        return moves;
    }
```

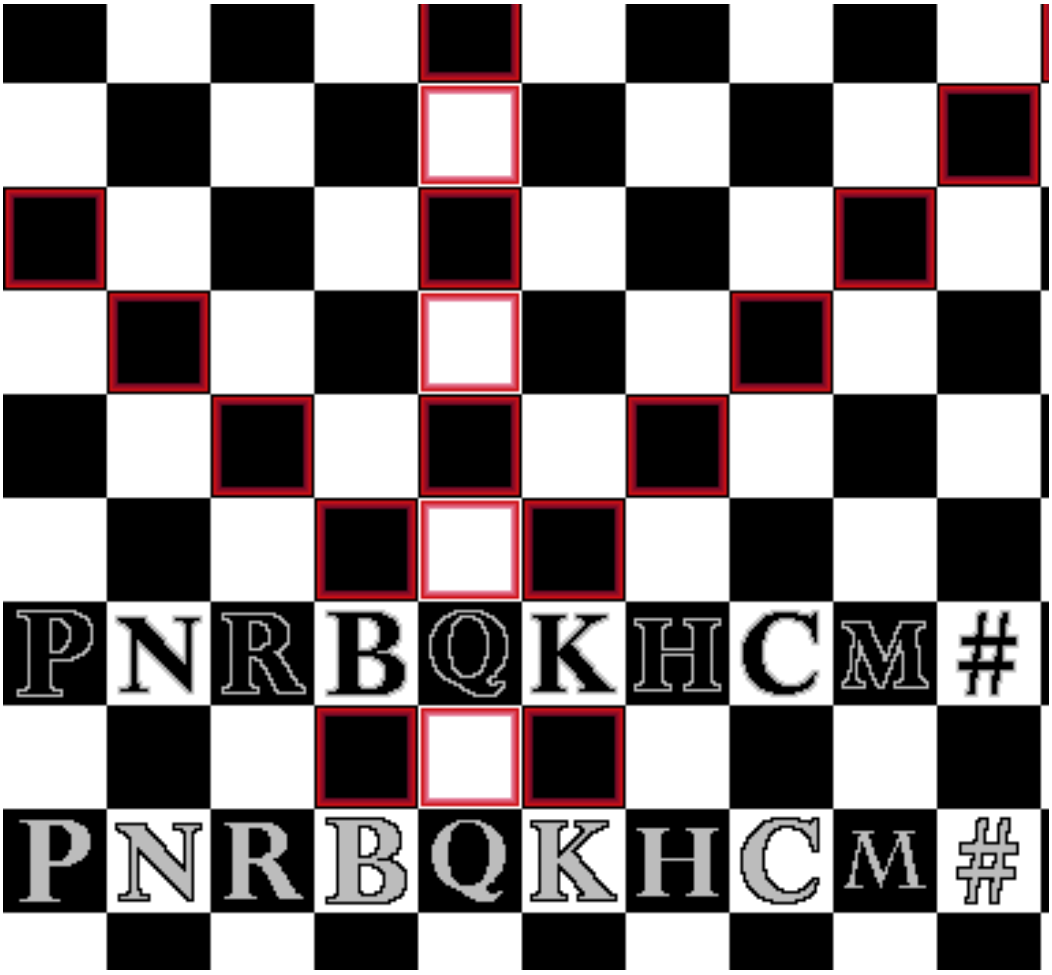
The two remaining pieces are the queen and chancellor. These will be simple to complete, because their movement is a combination of the movements of other pieces. A queen is a combination of the rook and the bishop, while the chancellor is a combination of the knight and the rook.

```
case PieceType.QUEEN: {
        moves.AddRange(new Piece(
            PieceType.BISHOP, square, PieceColour.WHITE).calculateMovement());
        moves.AddRange(new Piece(
            PieceType.ROOK, square, PieceColour.WHITE).calculateMovement());
        return moves;
    }
case PieceType.CHANCELLOR: { //KNIGHT + ROOK
        moves.AddRange(new Piece(
            PieceType.KNIGHT, square, PieceColour.WHITE).calculateMovement());
        moves.AddRange(new Piece(
            PieceType.ROOK, square, PieceColour.WHITE).calculateMovement());
        return moves;
    }
```

And their movements display as follows:



The movement calculation for all pieces seems to be complete. Before I do a thorough test for each piece in different situations, I will complete some minor related tasks. First, I have slightly improved the graphics for the movement being drawn by reducing the size of each drawn rectangle by one and making some of them more transparent:



The other thing I will do is add some functionality for changing the pieces on the board without having to change the code and recompile, because this will be useful for testing and debugging. I could create a configuration file that the program reads on startup and then will reread and update the board when I press a button, but this still involved me having to go to another program and change some configuration list. What I will do instead is add some keybinds to the board that will edit the piece in the square my cursor is currently over. To do this, I just need to overwrite the `OnKeyPress` method for `GameContainer` and add all the keybinds in there.

```
protected override void OnKeyPress(KeyPressEventArgs e)
{
    Label l = (Label)Parent.Controls.Find("debug3", false)[0];
    Button b = (Button)Parent.Controls.Find("begin", false)[0];

    Point a = Parent.PointToClient(new Point(Cursor.Position.X, Cursor.Position.Y));
    Square cursorSquare = findSquareByCoords(a.X - Location.X, a.Y - Location.Y);
    Piece target = null;
    foreach (Piece p in Chess.pieces) { if (p.square == cursorSquare) { target = p; } }

    if (cursorSquare != null) {
        if (target != null) {
            if (e.KeyChar == '\b') Chess.pieces.Remove(target);
            if (e.KeyChar == 'c') target.altColour();
        }
        else {
            switch (e.KeyChar) {
                case '0': {
                        Chess.pieces.Add(new Piece(PieceType.NONE, cursorSquare, PieceColour.WHITE));
                        break; }
                case '1': {
                        Chess.pieces.Add(new Piece(PieceType.PAWN, cursorSquare, PieceColour.WHITE));
                        break; }
                case '2': {
                        Chess.pieces.Add(new Piece(PieceType.BISHOP, cursorSquare, PieceColour.WHITE));
                        break; }
                case '3': {
                        Chess.pieces.Add(new Piece(PieceType.KNIGHT, cursorSquare, PieceColour.WHITE));
                        break; }
                case '4': {
                        Chess.pieces.Add(new Piece(PieceType.HAWK, cursorSquare, PieceColour.WHITE));
                        break; }
                case '5': {
                        Chess.pieces.Add(new Piece(PieceType.HAWK, cursorSquare, PieceColour.WHITE));
                        break; }
                case '6': {
                        Chess.pieces.Add(new Piece(PieceType.ROOK, cursorSquare, PieceColour.WHITE));
                        break; }
                case '7': {
                        Chess.pieces.Add(new Piece(PieceType.CHANCELLOR, cursorSquare, PieceColour.WHITE));
                        break; }
                case '8': {
                        Chess.pieces.Add(new Piece(PieceType.QUEEN, cursorSquare, PieceColour.WHITE));
                        break; }
                case '9': {
                        Chess.pieces.Add(new Piece(PieceType.KING, cursorSquare, PieceColour.WHITE));
                        break; }
            }

        }
        b.PerformClick();
    }
}
```

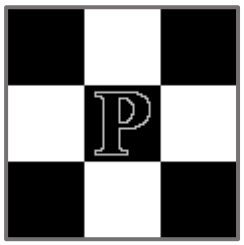
This code allows me to create new pieces by using the number keys, delete a piece using backspace, and alternate the colour of a piece using c.

Piece Movement Tests

Now I can begin testing the functionality of every piece. I will do a series of tests; for each, I will outline a starting configuration, explain the steps I will take, the expected outcome of those steps, and the actual outcome for those steps.

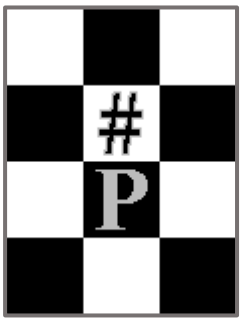
Lone Pawn

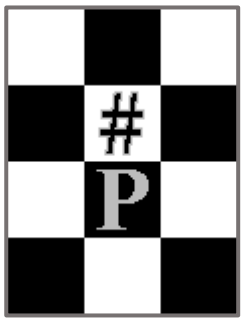
- The black pawn will be clicked
- The expected outcome is the square directly below the pawn becomes highlighted.
- The actual outcome was as expected.



Blocked Pawn

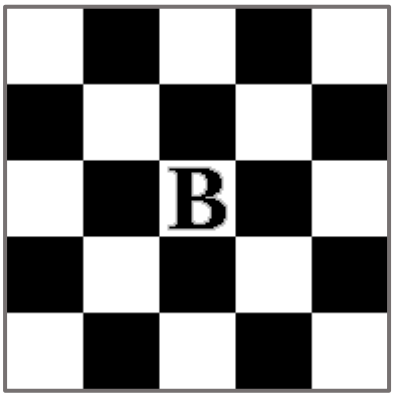
- The white pawn will be clicked.
- The expected outcome is no squares will become highlighted.
- The outcome was as expected

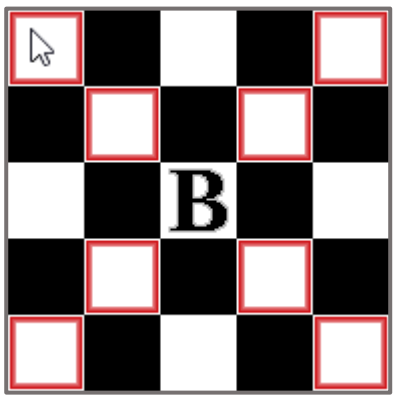




Lone Bishop

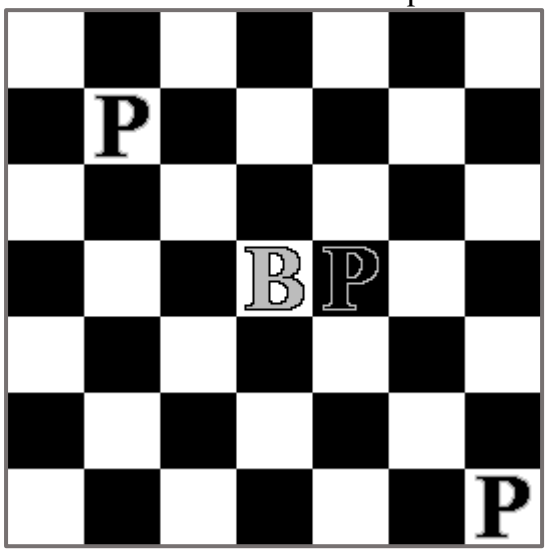
- The black bishop will be clicked.
- The squares which are diagonal from the bishop should become highlighted.
- The outcome was as expected.

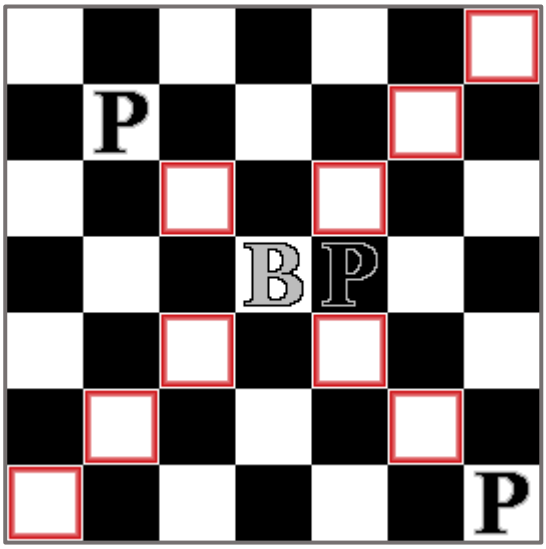




Doubly Blocked Bishop

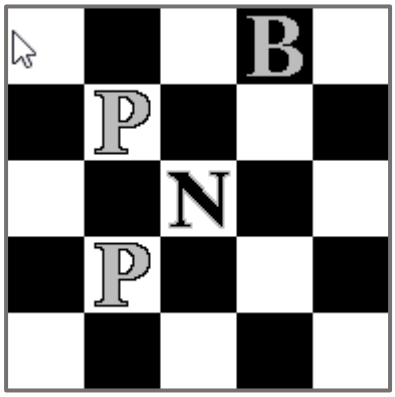
- The white bishop will be clicked.
- All squares on the top right and bottom left diagonals should become highlighted
- One square on the top left diagonal and two squares on the bottom right diagonal should become highlighted before being blocked by the pawns
- The outcome was as expected.

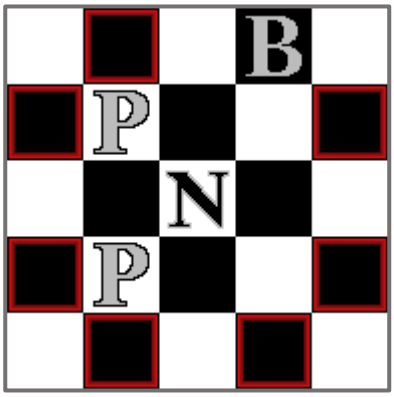




Blocked Knight

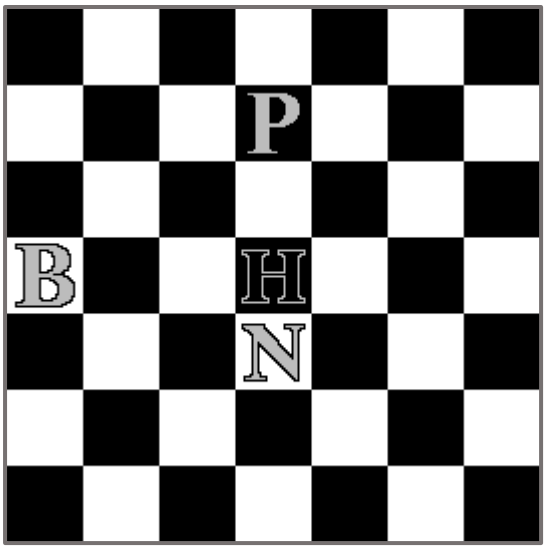
- The black knight will be clicked.
- All squares which are adjacent to the corners of the square shown apart from the one with a bishop in it should become highlighted.
- The outcome was as expected.

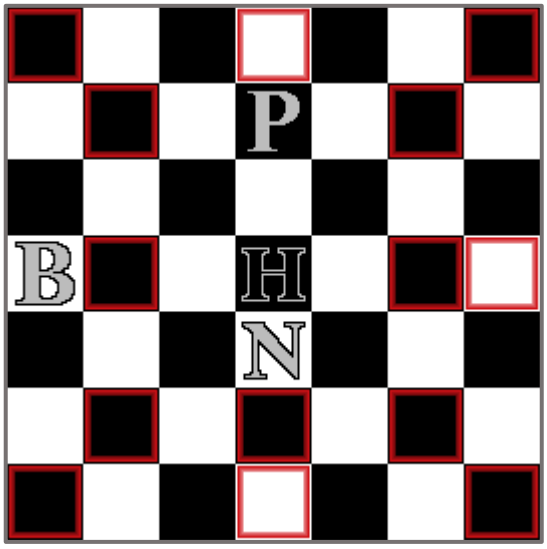




Doubly Blocked Hawk

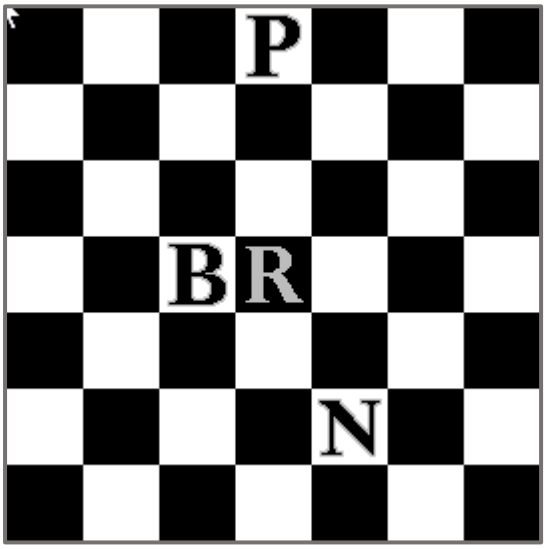
- The black hawk will be clicked.
- All squares which are two or three squares away from the hawk in any orthogonal or diagonal direction except the pieces occupied by the pawn and bishop should become highlighted.
- The outcome was as expected.

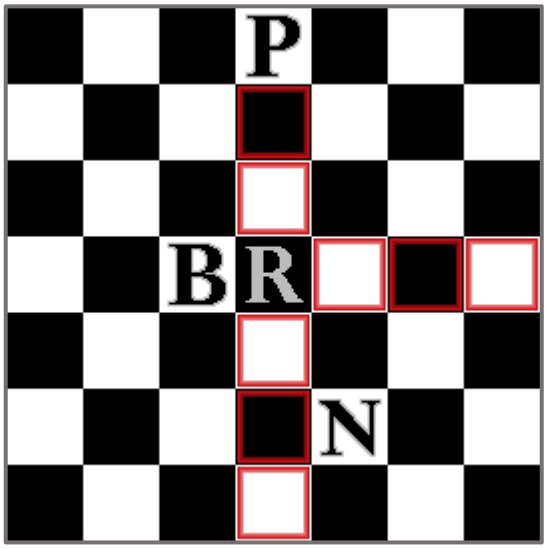




Doubly Blocked Rook

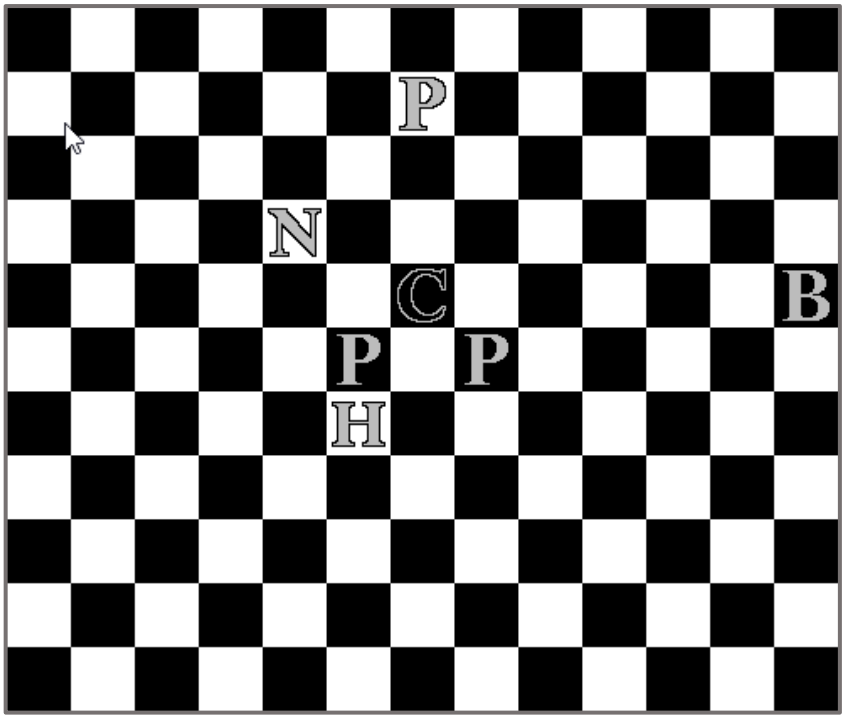
- The white rook will be clicked
- All squares to the right and below the rook should become highlighted
- Two squares above the rook should become highlighted, before being blocked by the pawn
- No squares to the left should be highlighted, since they are blocked by the bishop.
- The outcome was as expected.

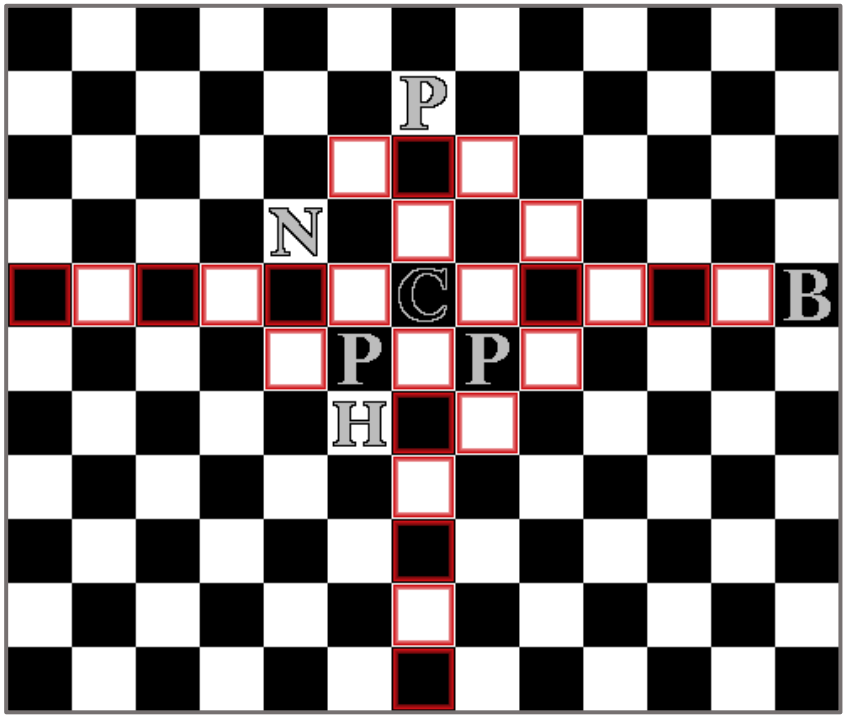




Blocked Chancellor

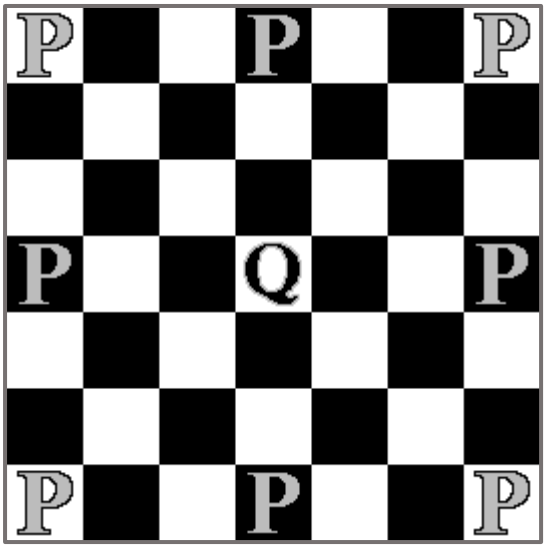
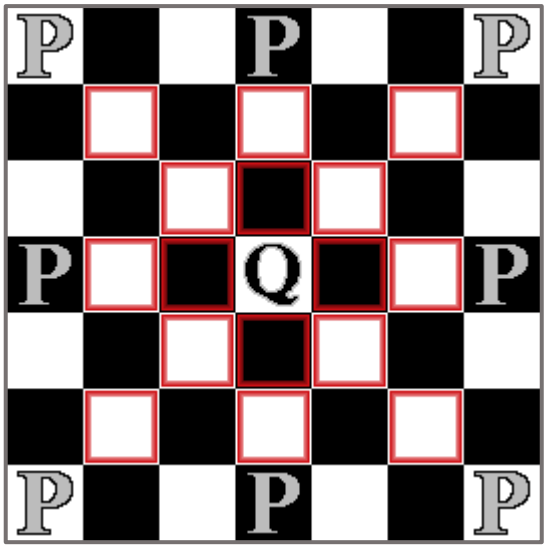
- The black chancellor will be clicked.
- All squares to the left and below the chancellor should become highlighted.
- Two squares above and five squares to the right should be highlighted before being blocked by the pawn and bishop, respectively.
- The squares which represent the movement of a knight should be highlighted, except for the one to the left blocked by the knight, and below blocked by the hawk.
- The outcome was as expected.





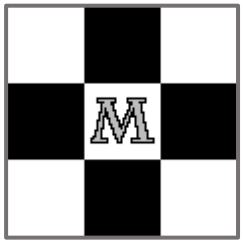
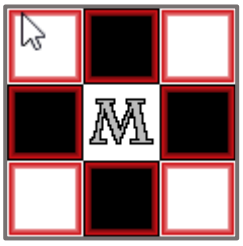
Blocked Queen

- The black queen will be clicked.
- Two squares in each orthogonal and diagonal direction should become highlighted, before being blocking by the pawns.
- The outcome was as expected.

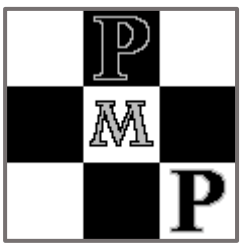
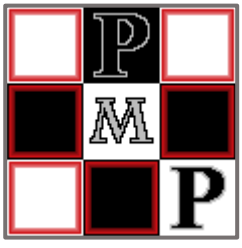
Lone Mann

- The black mann will be clicked.
- All adjacent squares should become highlighted.
- The outcome was as expected.

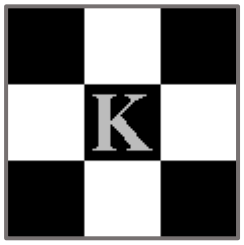
Blocked Mann

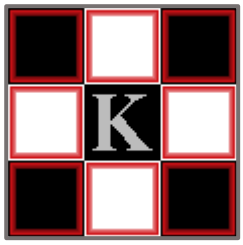
- The white mann will be clicked.
- All adjacent squares except the ones above and to the bottom right should become highlighted.
- The outcome was as expected.

Lone King

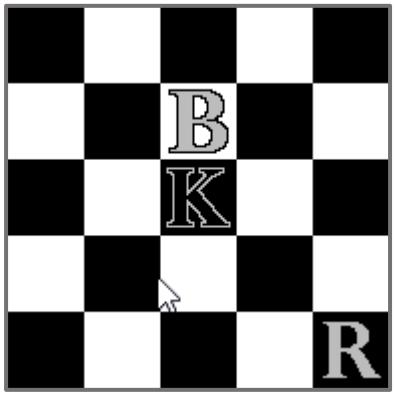
- The white king will be clicked.
- All adjacent squares should become highlighted.
- The outcome was as expected.

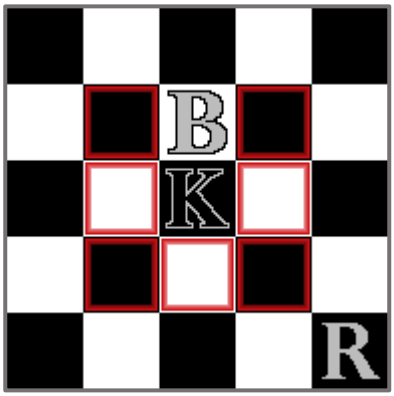




Blocked King

- The black king will be clicked.
- All adjacent squares except the one above blocked by the bishop should become highlighted.
- The outcome was as expected.



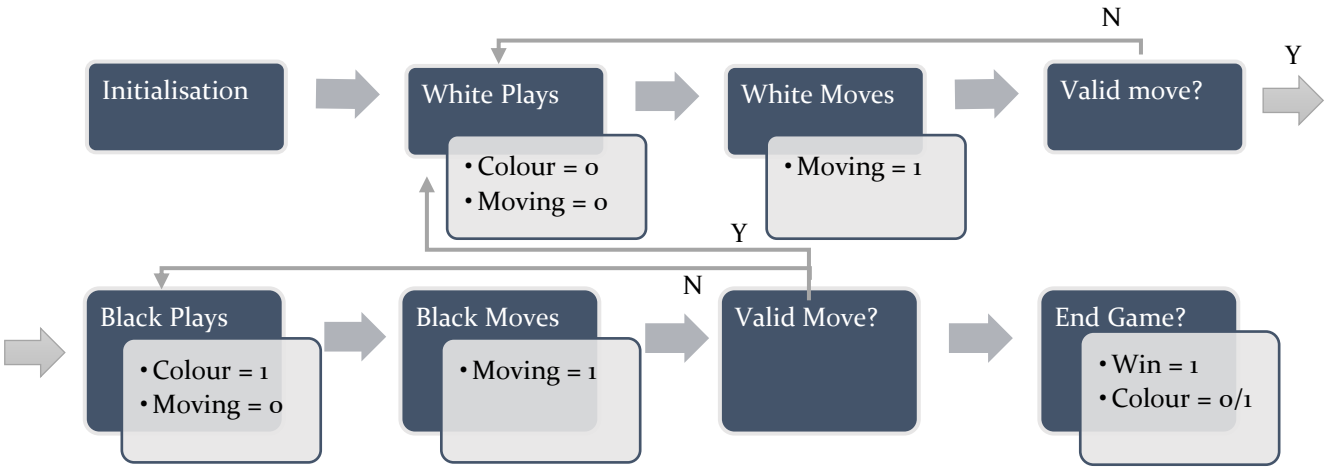


I can conclude, given the results of these tests, that the movement of all pieces is being properly calculated.

Turn Framework and Game States

Now that I know where pieces should move, the next logical thing to implement is making them actually move. Piece moving is a part of the turn-based system of the game (making sure the player can only move during their turn, and consequently that they can only move their pieces in their turn), and this requires some way to keep track of the current state of the game (i.e. who's turn it is). Since these things are all part of the same idea, they will all be implemented in this section.

The idea for the flow of the game is simple enough, and is illustrated in the diagram below; stages are named in the dark boxes, and the flow of the game is represented by arrows. The lighter boxes represent internal flags which will be set at each point so that the game can know what is happening at any point.



The enumerations I have been using previously are those in which only one value can be used at once (i.e. a piece can only be one type of piece). If I used this for the game states, I would need to create a separate entry in the enum for each combination of multiple factors. Instead, I can use a different type of enumeration which allows me to use combinational flags to describe the state. These can be applied in this situation because the state of the game can be described with a number of binary variables.

The definition of this enum looks like this:

```
[Flags] public enum State {
    Colour = 0x01, Move = 0x02, Check = 0x04, Win = 0x08, Stale = 0x0F
}
```

Each variable is represented by a single binary bit, so the entire state of the game is described with a 5-bit binary number. For example, if white has just caused a stalemate after putting black in check, the game would be described by 00101_2.

The useful thing about having these values represented as a binary number is that it simplifies getting and setting the state. For example, the code that decides whether to draw the movement of a piece or move a piece might look like the following if I was not using flags:

```
public void handleTurn() {
  if (state == GameState.PLAY_BLACK || state == GameState.PLAY_WHITE) {
    //find piece and draw its movement
    if (state == GameState.PLAY_BLACK) state = GameState.MOVING_BLACK;
    else state = GameState.MOVING_WHITE;
  }
  else if (state == GameState.MOVING_BLACK || state == GameState.MOVING_WHITE){
    //move piece
    if (state == GameState.MOVING_BLACK) state = GameState.PLAY_BLACK;
    else state = GameState.PLAY_WHITE;
  }
}
```

Using flags allows me to do binary arithmetic to toggle these values easily:

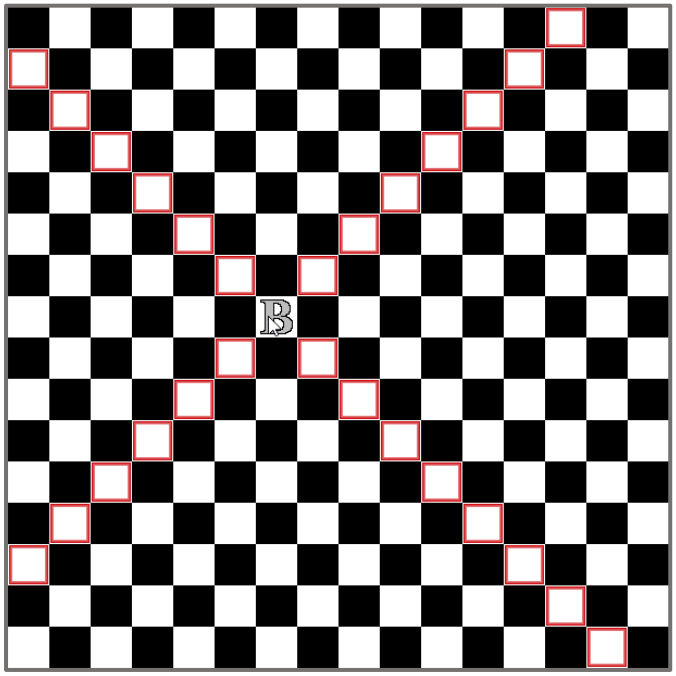
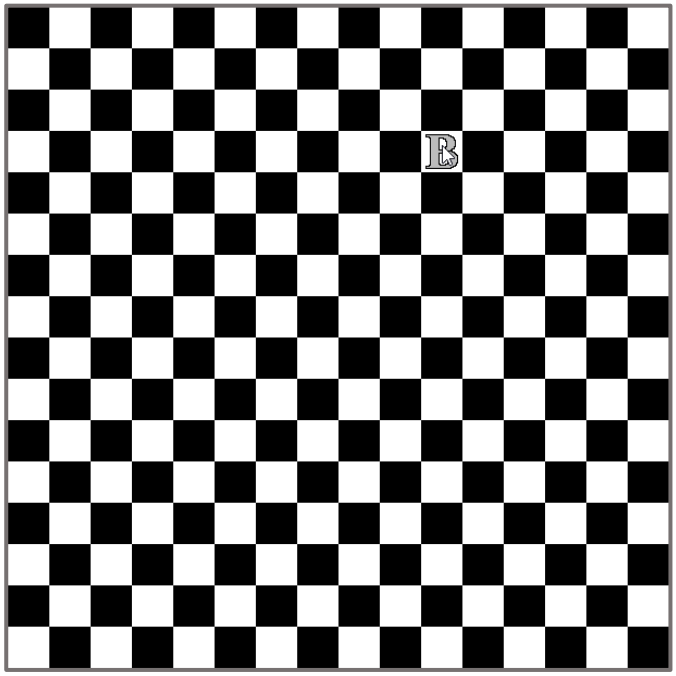
```
public void handleTurn() {
  if (!state.HasFlag(GameState.MOVING)) {
    //find piece and draw its movement
    state ^= GameState.MOVING;
  }
  else {
    //move piece
    state ^= (GameState.MOVING | GameState.COLOUR);
  }
}
```

Where `^` is the bitwise XOR operator and `|` is the bitwise OR operator.
When the game starts, `state` will have a value of `0x0`, meaning it is white's turn, there is no piece currently moving, no one is in check, neither player has won, and there is no stalemate.

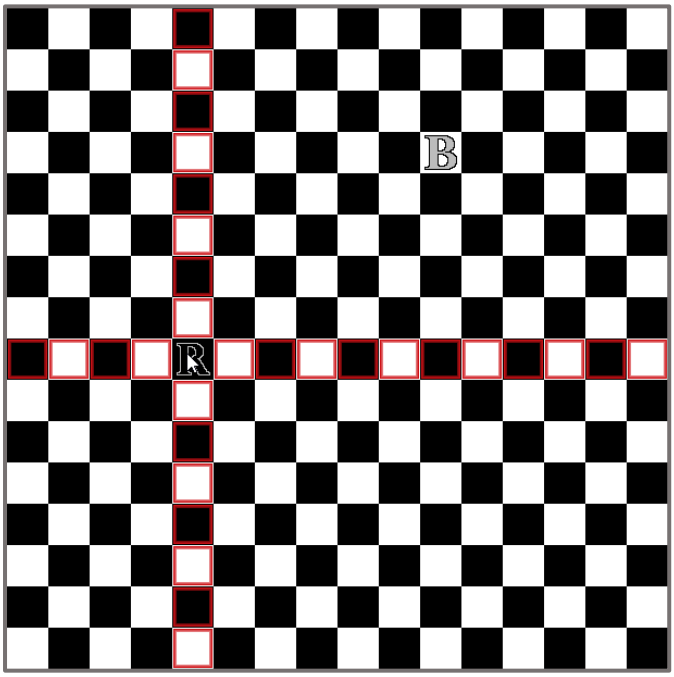
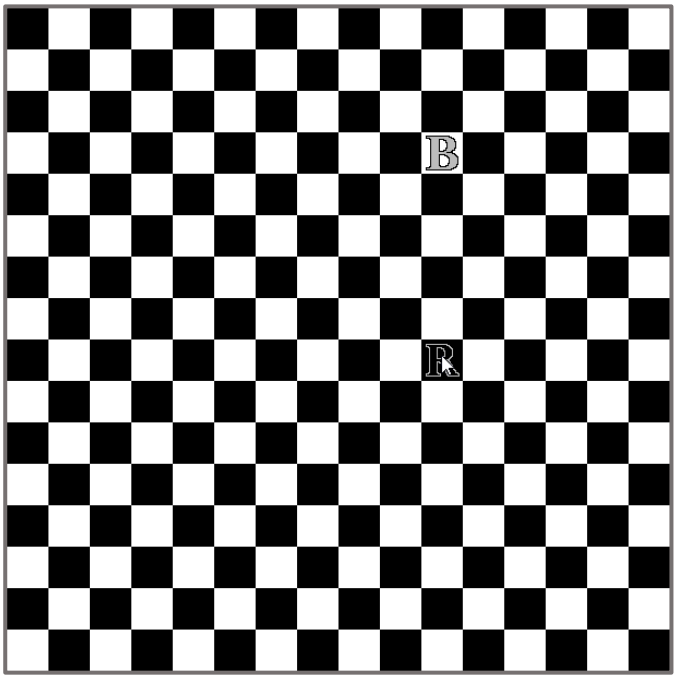
Turns will be handled by a function, `handleTurn`, which will be in `GameContainer`, and is called when a mouse click occurs somewhere on the board. There are two arguments, `Piece p` and `Square s`, that are passed into `handleTurn` by `OnMouseClick`. These arguments represent the piece that was under the mouse cursor when the click occurred (which may be null), and the square the cursor was over. Implementing the flowchart and algorithm gives the following:

```
public void handleTurn(Piece p, Square s) {
    if (!state.HasFlag(GameState.MOVE)) {
        if (p!= null && !state.HasFlag(GameState.COLOUR) == p.colour.HasFlag(PieceColour.WHITE)) {
            pieceMoving = p;
            drawMoves(p);
            state ^= GameState.MOVE;
        }
    }
    else {
        if (pieceMoving.calculateMovement().Contains(s)) {
            pieceMoving.move(s);
            state ^= (GameState.MOVE | GameState.COLOUR);
        }
        else state ^= GameState.MOVE;
        c.drawBoard();
        pieceMoving = null;
    }
}
```

To test it out, I start the game and create a bishop. Since white moves first, the bishop must be white. Clicking it drew the possible moves for the bishop, and then clicking one of the highlighted squares moved the bishop to that square. Clicking the bishop again afterwards did nothing, since it is now black's turn.

I create a black rook and click it. This causes the rook movement to become highlighted. I click one of the highlighted squares again and the rook moves.

If after clicking a piece to show the moves I click a non-highlighted square, the highlighted squares disappear but I can click the piece again. A turn does not end until a piece moves.

Capturing Pieces

Capturing pieces is of course an integral part of chess, and since pieces can move and turns are implemented, this seems like the next logical step.

I will need to re-write some of the movement calculation code, because currently a square which has another piece on will never be returned as a valid move. However, to be able to capture pieces I will want squares which have pieces of the opposite colour to be valid moves.

The function I wrote earlier, `checkSquareForPiece`, returns true if it finds a piece in the given square, or false if otherwise. This is no longer enough information; I need to know if the piece is white or black (i.e. is it capturable). To account for this, I can change the return type of the function to be an `int`, and return `0` for no piece, `1` for a capturable piece, and `2` for a non-capturable piece. Kings are an exception; they are never capturable, so if the piece is a King `2` will be returned.

```
public static int checkSquareForPiece(Square s) {
    foreach (Piece p in pieces) {
        if (p.square == s) {
            if (p.type == PieceType.KING) return 2;
            if (state.HasFlag(GameState.COLOUR) == p.colour.HasFlag(PieceColour.WHITE))
                return 1;
            else return 2;
        }
    }
    return 0;
}
```

This cannot be tested straight away, since there are now errors elsewhere. In the movement calculation section, I used this function as a boolean value, but now it is an int, so I will need to update to account for this.

Pawn

```
case (PieceType.PAWN): {
        var direction = colour == PieceColour.WHITE ? square.indexY + 1 : square.indexY - 1;
        Square attempt = Chess.GameContainer.findSquareByIndex(square.indexX, direction);
        if (!Chess.checkSquareForPiece(attempt)) moves.Add(attempt);
        return moves;
    }
```

For the pawn there is a caveat, they cannot capture forwards, only diagonally. This means we need to add another check. For the original check, we will only add the move to the list if the function returns `0` (no piece). Using a `for` loop, I can check both the forward diagonals. These should only be added to the list if the function returns `1` (there is a capturable piece).

```
case (PieceType.PAWN): {
        int direction = colour == PieceColour.WHITE ? square.indexY + 1 : square.indexY - 1;
        Square attempt = Chess.GameContainer.findSquareByIndex(square.indexX, direction);
        if (Chess.checkSquareForPiece(attempt) == 0) moves.Add(attempt);
        for (int i = -1; i <= 1; i += 2) {
            attempt = Chess.GameContainer.findSquareByIndex(square.indexX + i, direction);
            if (Chess.checkSquareForPiece(attempt) == 1) moves.Add(attempt);
        }
        return moves;
    }
```

This code can actually be simplified into fewer lines. When I am adding 0 to indexX, I will add the move if the result is 0. If I am adding or subtracting 1, I will add the move if the result is 1.

```
case (PieceType.PAWN): {
        int direction = colour == PieceColour.WHITE ? square.indexY + 1 : square.indexY - 1;
        for (int i = -1; i <= 1; i++) {
            Square attempt = Chess.GameContainer.findSquareByIndex(square.indexX + i, direction);
            if (Chess.checkSquareForPiece(attempt) == Math.Abs(i)) moves.Add(attempt);
        }
        return moves;
    }
```

Bishop

```
case (PieceType.BISHOP): {
    bool[] tracker = { false, false, false, false };
    int[][] direction = type == PieceType.BISHOP ?
        new int[][] { new int[]{-1,-1}, new int[]{-1,1}, new int[]{1,-1}, new int[]{1,1} } :
        new int[][] { new int[]{-1,0}, new int[]{1,0}, new int[]{0,-1}, new int[]{0,1} };
    int max = Chess.findLargest(new int[] {
        square.indexX-Chess.bounds[0], square.indexY-Chess.bounds[2],
        Chess.bounds[1]-square.indexX, Chess.bounds[3]-square.indexY} );
    for (int i = 1; i <= max; i++) {
        for (int j = 0; j < 4; j++) {
            if (!tracker[j]) {
                Square attempt = Chess.GameContainer.findSquareByIndex(
                    square.indexX - i*direction[j][0], square.indexY - i*direction[j][1]) ?? square;
                tracker[j] = Chess.checkSquareForPiece(attempt);
                if (!tracker[j]) moves.Add(attempt);
            }
        }
    }
    return moves;
```

`tracker` will need to be updated to not be a `bool`. Instead, it will start off as an array of zeroes, and then at each pass through the first `for` loop, will be set to the value of the result of the function. Then, if the tracker value is `0`, the move is added. If it is `2`, the move is not added. If it is `1`, the move is added, and then the tracker value is set to `2`. The initial `if` statement in the loop will then be changed to `if(tracker[j] != 2)`.

```
case (PieceType.BISHOP): {
    int[] tracker = { 0, 0, 0, 0 };
    int[][] direction = type == PieceType.BISHOP ?
        new int[][] { new int[]{-1,-1}, new int[]{-1,1}, new int[]{1,-1}, new int[]{1,1} } :
        new int[][] { new int[]{-1,0}, new int[]{1,0}, new int[]{0,-1}, new int[]{0,1} };
    int max = Chess.findLargest(new int[] {
        square.indexX-Chess.bounds[0], square.indexY-Chess.bounds[2],
        Chess.bounds[1]-square.indexX, Chess.bounds[3]-square.indexY} );
    for (int i = 1; i <= max; i++) {
        for (int j = 0; j < 4; j++) {
            if (tracker[j] != 2) {
                Square attempt = Chess.GameContainer.findSquareByIndex(
                    square.indexX - i*direction[j][0], square.indexY - i*direction[j][1]) ?? square;
                tracker[j] = Chess.checkSquareForPiece(attempt);
                if (tracker[j] != 2) {
                    moves.Add(attempt);
                    if (tracker[j] == 1) tracker[j] = 2;
                }
            }
        }
    }
    return moves;
}
```

King

```
case (PieceType.KING): {
        string[] attempts = File.ReadAllLines($"res/movement/{type.ToString()}.txt");
        foreach (string att in attempts) {
            Square s = Chess.GameContainer.findSquareByIndex(
                square.indexX + int.Parse(att.Split(',')[0]),
                square.indexY + int.Parse(att.Split(',')[1]));
            if (!Chess.checkSquareForPiece(s) && s != null) moves.Add(s);
        }
        return moves;
    }
```

This will just be a simpler version of the pawn fix. All that needs to be done is change the last if statement to `if (Chess.checkSquareForPiece(s) != 2 && s != null)`:

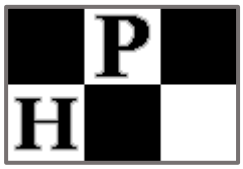
```
case (PieceType.KING): {
        string[] attempts = File.ReadAllLines($"res/movement/{type.ToString()}.txt");
        foreach (string att in attempts) {
            Square s = Chess.GameContainer.findSquareByIndex(
                square.indexX + int.Parse(att.Split(',')[0]),
                square.indexY + int.Parse(att.Split(',')[1]));
            if (Chess.checkSquareForPiece(s) != 2 && s != null) moves.Add(s);
        }
        return moves;
    }
```

All other pieces call the code of one of the pieces already covered, to they are also fixed. I can now do some testing for these new calculations since all errors are fixed.

Pawn

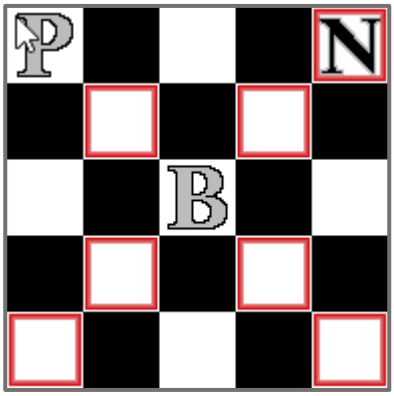
- The white pawn will be clicked.
- The upper right square should become highlighted. The other two should be blocked by the knight and bishop.
- The outcome was as expected.

- The black pawn will be clicked.
- The square below the pawn should become highlighted.
- The outcome was as expected.



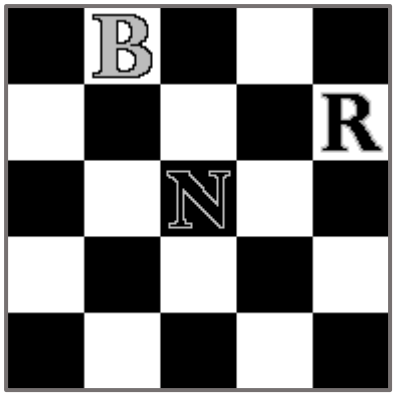
Bishop

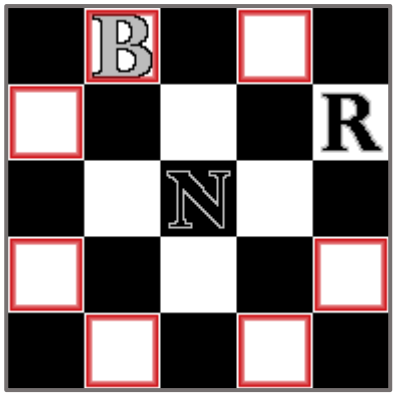
- The white bishop will be clicked.
- The black knight should become highlighted, and the white pawn should not.
- The outcome was as expected.



Knight

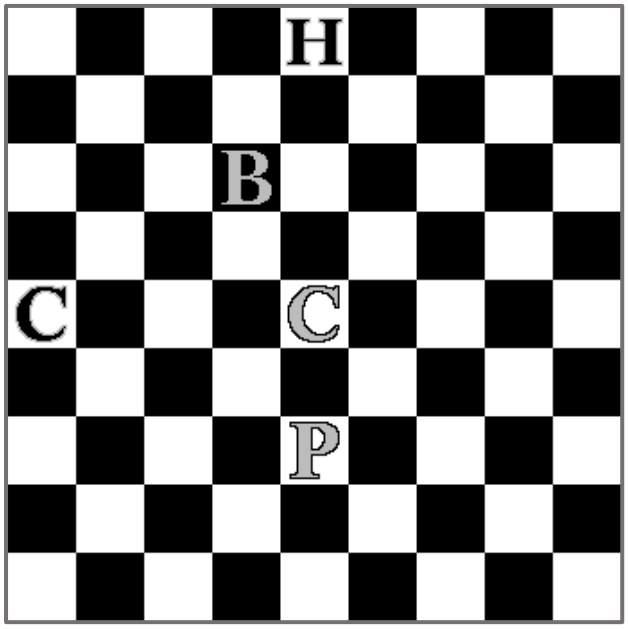
- The black knight will be clicked.
- The white bishop should become highlighted, and the black rook should not.
- The outcome was as expected.

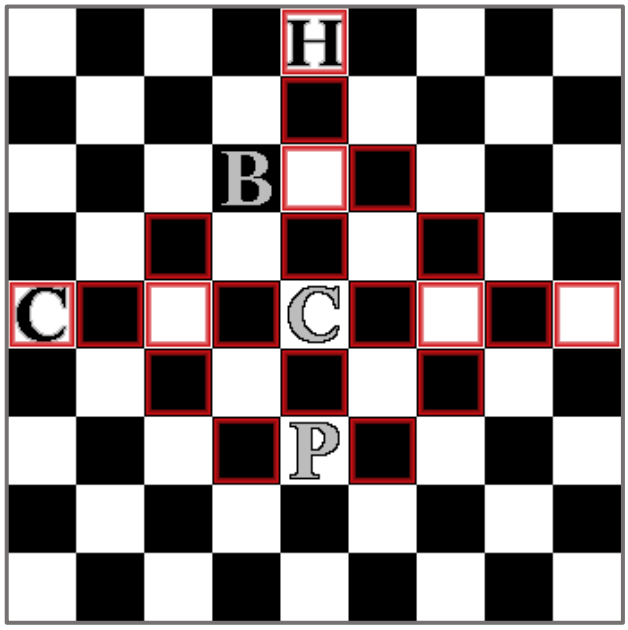




Chancellor

- The white chancellor will be clicked.
- The upper line should include the black hawk and then stop. The left line should include the black chancellor and then stop.
- The lower line should be blocked by the white pawn.
- The white bishop should not become highlighted.
- The outcome was as expected.



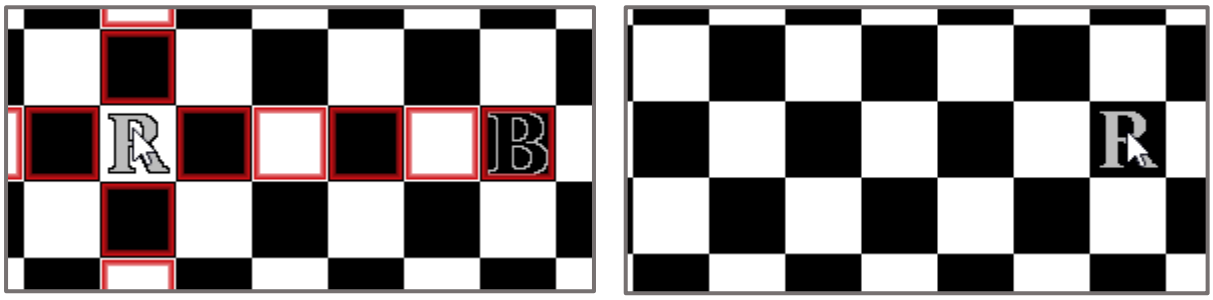


I can conclude that piece movement calculations correctly take into account the possibility of capturing enemy pieces.

Currently, even though I can move a piece onto the same square as another, that isn't actually capturing. I need to remove a piece from the game once it gets captured. The most sensible place to implement this is in the `move` function. When a move is selected, the game will check if the selected move has a piece on it already. If there is a piece there, it will be removed.

```
public void move(Square s) {
    foreach (Piece p in Chess.pieces) {
        if (p.square == s) { Chess.pieces.Remove(p); break; }
    }
    square = s;

}
```

Testing it out:



It looks to be working fine.

Check and Checkmate

To put the game into a state where it is playable, there needs to be a concept of check and checkmate.

After every turn, some function will be run which checks the movement of each piece, and if one of them contains the king of the opposite colour, the check flag will be set, meaning on the next turn only the king can be moved, and it must be moved in a way which puts it out of check.

Currently there is an issue, the calculate movement function does not include kings of the opposite colour, because these should not be capturable. However, if I changed the function to include them, they would be shown as capturable to the player. What I need is one function for the player, and one for the check function.

To do this, I can make `calculateMovement` take a parameter, `includeKings`, which will determine whether kings will be included. The best way to make this work will be to add another parameter to `checkSquareForPiece` which will decide if the condition which returns `2` if the piece is a king is active.

The updated `checkSquareForPiece` looks like this:

```
public static int checkSquareForPiece(Square s, bool includeKings) {
    foreach (Piece p in pieces) {
        if (p.square == s) {
            if (p.type == PieceType.KING && !includeKings) return 2;
            if (state.HasFlag(GameState.COLOUR) == p.colour.HasFlag(PieceColour.WHITE))
                return 1;
            else return 2;
        }
    }
    return 0;
}
```

And the beginning of the updated movement calculation function:

```
public List<Square> calculateMovement(bool includeKings) {
    List<Square> moves = Square.emptyList();
    switch (type) {
        case (PieceType.PAWN): {
                int direction = colour == PieceColour.WHITE ? square.indexY + 1 : square.indexY - 1;
                for (int i = -1; i <= 1; i++) {
                    Square attempt = Chess.GameContainer.findSquareByIndex(square.indexX + i, direction);
                    if (Chess.checkSquareForPiece(attempt, includeKings) == Math.Abs(i)) moves.Add(attempt);
                }
                return moves;
            }
```

The only thing that has changed is the addition of the extra parameter throughout the function.

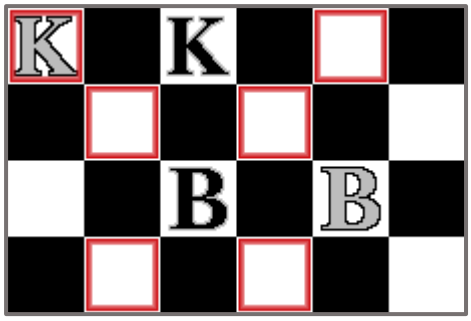
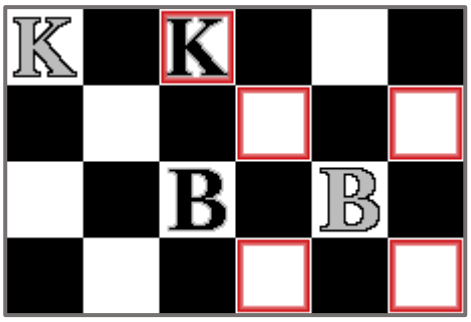
The first iteration of `evaluateCheck` function looks like this:

```
public void evaluateCheck() {
    var colour = state.HasFlag(GameState.COLOUR) ? PieceColour.BLACK : PieceColour.WHITE;
    Square king = pieces.Find(p => p.type == PieceType.KING && p.colour == colour).square;

    foreach (Piece p in pieces) {
        if (p.calculateMovement(true).Contains(king)) {
            state ^= GameState.CHECK; break;
        }
    }
}
```

This function is called every time a piece moves. I also have a debug label set up to display the game state every time `handleTurn` is called. I can use this to see if this function is working correctly. During normal gameplay, `state` alternates between `0` and `1` (representing white and black's turn, respectively). Check, being the third flag in `GameState`, adds `4` to `state` if it is set. This means that if white is put into check, I would expect to see a value of 4, and for black a value of 5.

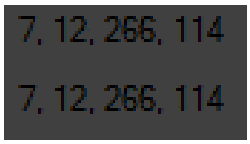
I test this by creating one king of each colour and a bishop of each colour. However, the label only ever has a value of 1 or 0, even if the pieces move to a location which would put one of the kings into check.

I'm not sure where the problem is, so I will begin by making sure the updated `calculateMovement` function is working. To do this, I will simply adjust `drawMoves` to draw the result of `cal culateMovement(true)` instead of `calculateMovement(false)`.

The kings are being included, as expected, so it seems this is not the issue.

The next thing to try is if `king`, the square which will contain the king of the opposite colour, is valid and correct. To do this I can set up the debug label to output the coordinates of this square and compare it using the other debug label which will output the square the cursor is currently over. However, this does not seem to be the issue either, as after moving a white piece and hovering over the black king, both labels have the same value.

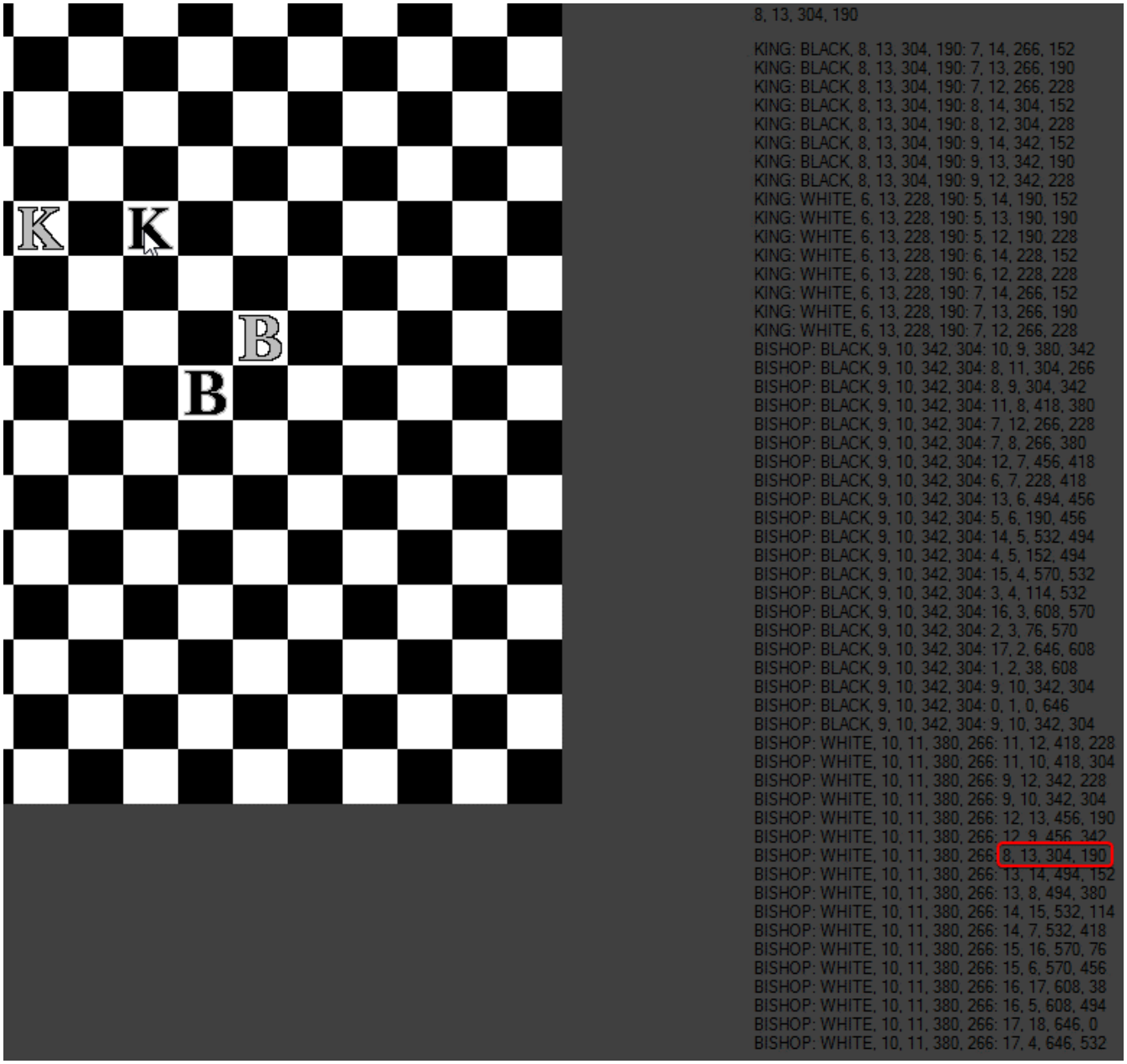


Next, I will check if my condition for setting the state is correct. I will do this by adding the following line of code into the `foreach` loop:

```
c.debug3.Text += p.calculateMovement(true).Contains(king).ToString();
```

This will tell me the value of this condition for each piece on the board. If it is working correctly, I would expect one of these to be true. However:

I would have expected to find the problem by now. Since I haven't, I will need to display more information. I decide that the next thing to do should be to list each Square contained in the movement for each piece.



The black king is at [8,13]. The bishop is in a position to put this king in check, so its movement should include it. As can be seen, the highlighted value shows the square that the king is on, meaning the list of available movement does contain the square the king is on, so there is a problem with the method I have used to decide whether a list contains a square.

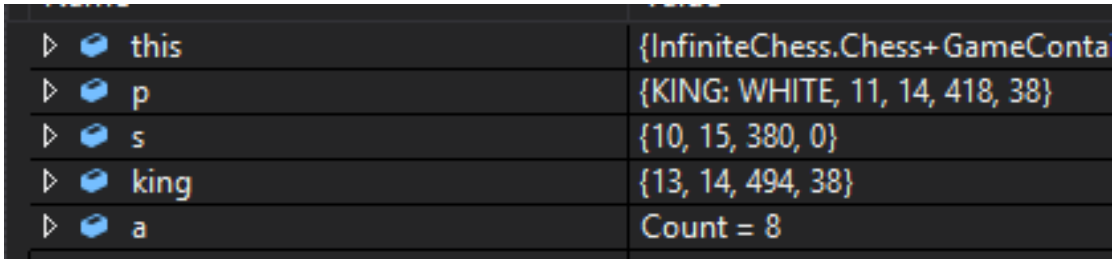
After doing some research, `.Contains` uses the default equality check for the specified object type. I have not defined one specifically for `Square`, and I don't know the exact method it uses to compare otherwise, so I will try overriding this method to see if that fixes the problem.

This is done using the following:

```
public bool Equals(Square s) => (X == s?.X && Y == s?.Y && indexX == s?.indexX && indexY == s?.indexY);
public override bool Equals(object obj) {
    if (obj == null) return false;
    Square s = obj as Square;
    if (s == null) return false;
    else return Equals(s);
}
public override int GetHashCode() => X.GetHashCode() ^ Y.GetHashCode() ^ indexX.GetHashCode() ^ indexY.GetHashCode();
```

I have to write three functions. The first compares two `Squares` with each other, the second compares an `object` with an instance of `Square` (this is the method used by `.Contains`, this method also uses the first method), and the third generates the hash code for an instance of `Square`. I do not actually need this, but it is required that this method is overrode if `Equals` is, and vice versa.

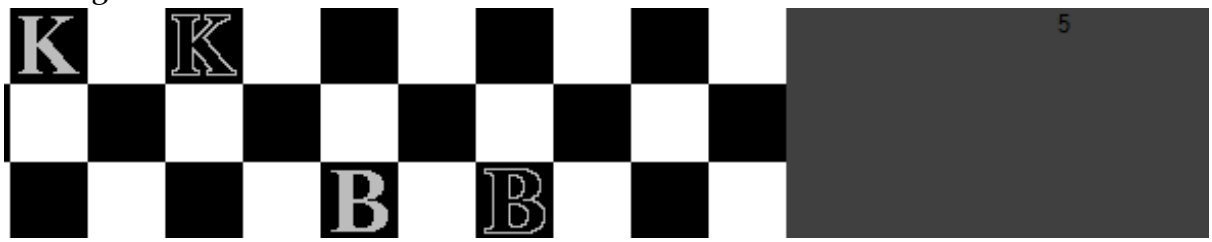
Unfortunately, this does nothing. My last resort is to set a breakpoint in `evaluateCheck` and step through the code line-by-line to see what is happening, using the watch feature to see the values of important variables:



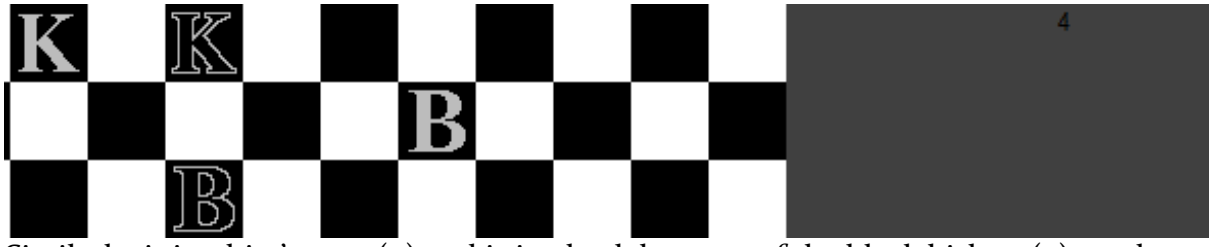
After a lot of pressing the next line button, I finally find the problem. In `checkSquareForPiece`, I check the colour of the piece being processed against the colour of the current turn (stores in state). This was assuming that the function is called during a turn (i.e. before the colour is updated in state). However, evaluteCheck is called after the state has already been updated. This was causing the movement function to not be adding the square with the opposite colour king (instead it was adding the same colour king), and therefore the game could never enter check. To fix this, I move `evaluateCheck` to be before the updating of `state`, and swap around the colour of king to look for in relation to the current state. The new version looks like this:

```
public void evaluateCheck() {
    var colour = state.HasFlag(GameState.COLOUR) ? PieceColour.WHITE : PieceColour.BLACK;
    Square king = pieces.Find(p => p.type == PieceType.KING && p.colour == colour).square;
    foreach (Piece p in pieces) {
        if (p.calculateMovement(true).Contains(king) && p.colour != colour) {
            state ^= GameState.CHECK; break;
        }
    }
}
```

Testing this:



It is black's turn (state contains 1), and black is in check because of the white bishop (state contains 4), therefore the state should be 4+1=5, which can be seen on the right.



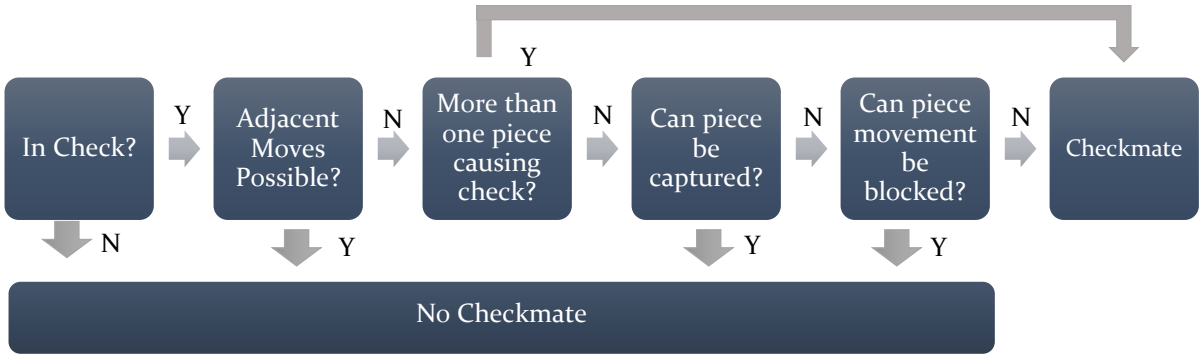
Similarly, it is white's turn (0) and is in check because of the black bishop (4), so the state should be 0+4=4, which is what it actually is.

Moving out of check does not actually update the state, since the state is only updated when the check condition is met (in which case the state is flipped). To fix this, I will just remove the check flag from the state if it is enabled every time `evaluateCheck` is called:

```
if (state.HasFlag(GameState.CHECK)) { state ^= GameState.CHECK; }
```

A side effect of this is that if one player is put into check, they will be automatically removed from it as far as the state is concerned after their turn is over. Currently, this leads to some strange behaviour, but one of the rules of chess is that if you are in check then you have to make a move which will put you out of check. This means that there is no need to deal with this side effect right now, as it will be intended behaviour soon enough.

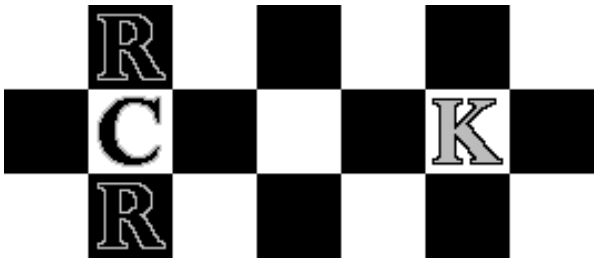
Dealing with checkmate will be a little more challenging. If one player is in checkmate, it means that they are in check, but also there are no available squares for the king to move, and no other piece can make a move which will remove the king from check (by capturing or blocking). The following diagram represents the process I will use to determine checkmate:



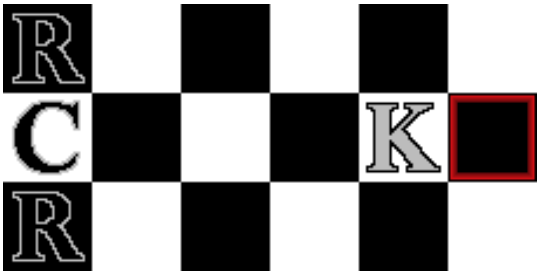
I have just completed the ability to determine whether a player is in check, so the next step is to be able to check if any of the squares adjacent to the king can be moved to. If there are squares that the king can move to that would not put it in check, then it cannot be in checkmate. I can add this as an extension of calculatePieceMovement for only the king pieces:

```
case (PieceType.KING): {
        string[] attempts = File.ReadAllLines($"res/movement/{type.ToString()}.txt");
        foreach (string att in attempts) {
            Square s = Chess.GameContainer.findSquareByIndex(
                square.indexX + int.Parse(att.Split(',')[0]),
                square.indexY + int.Parse(att.Split(',')[1]));
            if (Chess.checkSquareForPiece(s, includeKings) != 2 && s != null) moves.Add(s);
        }
        if (type != PieceType.KING) return moves;
        for (int i = -1; i < 2; i++) {
            for (int j = -1; j < 2; j += (2 - Math.Abs(i))) {
                foreach (Piece p in Chess.pieces) {
                    Square attempt = Chess.GameContainer.findSquareByIndex(square.indexX + i, square.indexY + j);
                    if (p.type != PieceType.KING & p.colour != colour) {
                        if (p.calculateMovement(false).Contains(attempt))
                        moves.Remove(attempt);
                    }
                }
            }
        }
        return moves;
    }
```

This will check if there are any pieces of the opposite colour which can move to one of the squares around the king, and removes it from the list of available moves if necessary. This works in most cases, but there are some cases where this logic does not apply. For example, consider the following scenario:



This is a checkmate (assuming there are no other pieces on the board), there is nowhere the king can move to avoid check. However, if we try to move the king, the algorithm above returns the following:

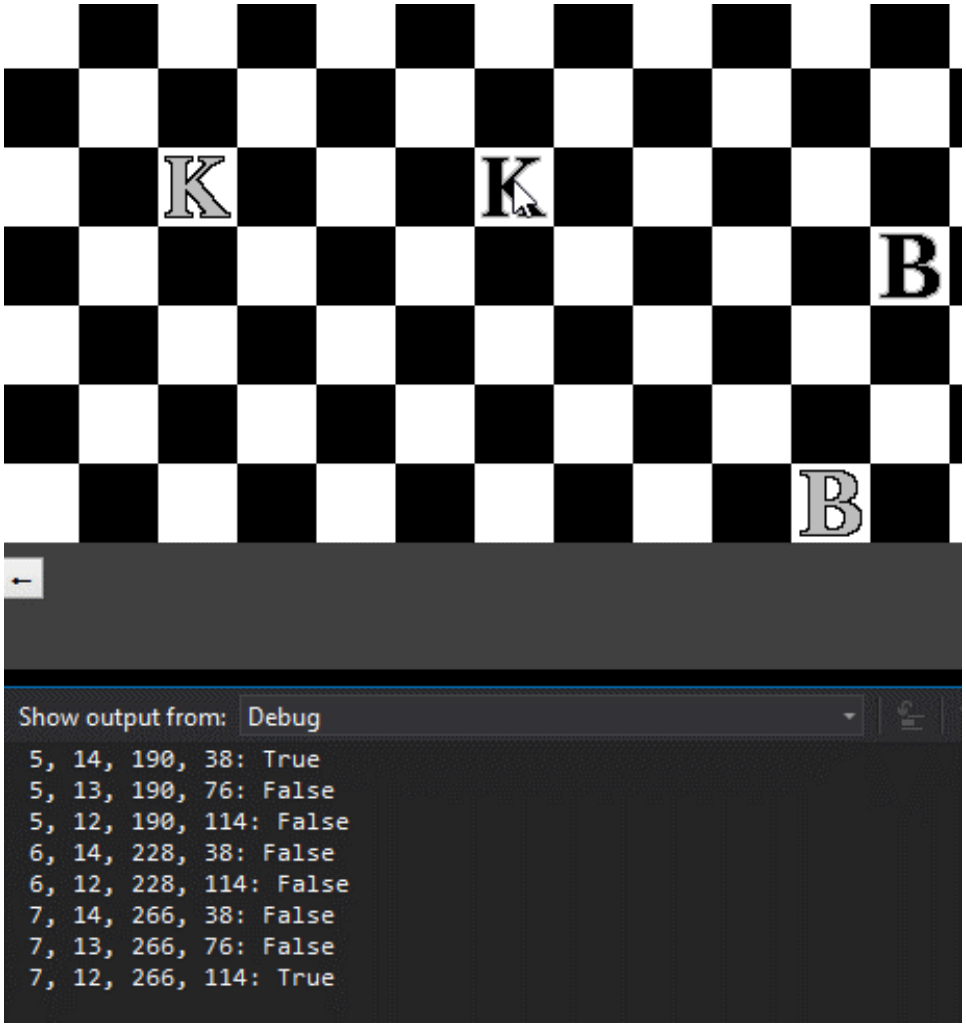


This is because when the movement of the king is being evaluated, that square is not part of the available movement of the chancellor, because it is being blocked by the king. However, once the king moves there, it is no longer being blocked. This means I will need a different approach to the problem.

A different solution would be to iterate through each possible move for the king and evaluate check for this new board. To check if it is working correctly initially, I will use `Debug.WriteLine` to write each square tested and the outcome of the check for that square when checkmate is evaluated. The first iteration of the function looks like this:

```
public void evaluateCheckMate(PieceColour c) {
    Piece king = pieces.Find(p => p.type == PieceType.KING && p.colour == c);
    Square original = king.square;
    foreach (Square s in king.calculateMovement(false)) {
        king.move(s);
        var a = evaluateCheck(c);
        Debug.WriteLine($"{s.ToString()}: {a}");
    }
    king.move(original);
}
```

The black king is at [6,13], and the bishop was moved to put it into check. Given this arrangement, I would expect [7,12] and [5,14] to return `true` (moving to these squares would put the king in check), and the others to return `false`.



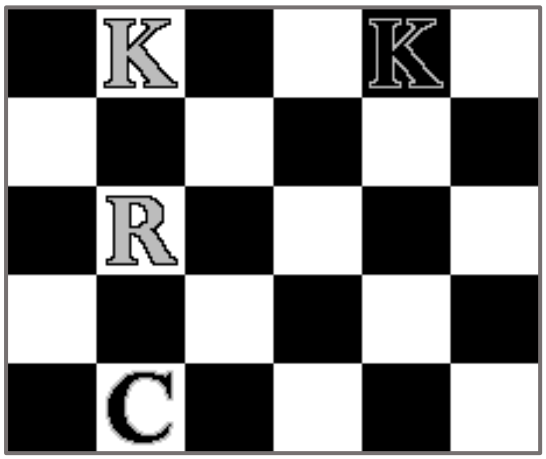
This was the output, which is in line with the expectations. However, in future, I will want to be able to draw these to the board, because the output of this function will represent the actual available movement for the king (as opposed to the

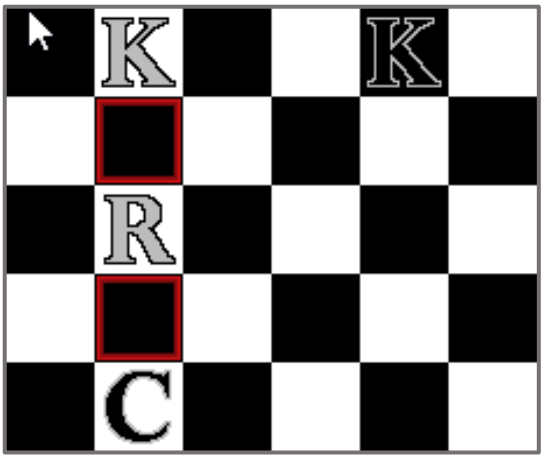
`calculateMovement` function, which does not consider check). Not only this, but I will also need to consider a similar case for other pieces; if a piece is blocking the line between an enemy piece and a king, then this piece cannot move out of the way so as to cause check. To solve this, I need to add some form of check for check in the movement calculation function. However, the current `evaluateCheck` contains `calculateMovement` calls in it already. A way around this would be to have a 'primitive' movement calculation which does not take check into account, and then another function which will take the result from that function, try every move, and then remove any which would cause check. Combined, these should give valid movement for all pieces, taking the possibility of check into account.

I have renamed the previous movement function to `calculateInitMovement`, and then added a new `calculateMovement` as follows:

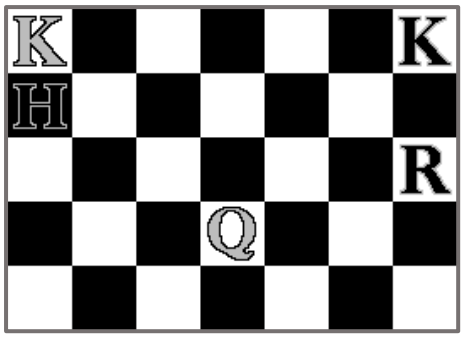
```
public List<Square> calculateMovement(bool includeKings) {
    List<Square> moves = calculateInitMovement(includeKings);
    List<Square> newMoves = new List<Square>();
    Square original = square;
    foreach (Square s in moves) {
        newMoves.Add(s);
        move(s);
        Square king = Chess.pieces.Find(p => p.type == PieceType.KING && p.colour == colour).square;
        foreach (Piece p in Chess.pieces) {
            if (p.colour == colour) continue;
            if (p.calculateInitMovement(true).Contains(king)) { newMoves.Remove(s); }
        }
        move(original);
    }

    return newMoves;
}
```

To test it out, I have the scenario on the left. The rook is blocking the white king rom being in check via the black chancellor. If the rook were to move to either side, the king would be in check. This means that moving to either side should not be a valid move. Clicking the white rook yields the following moves, which are indicative that this code works as expected.

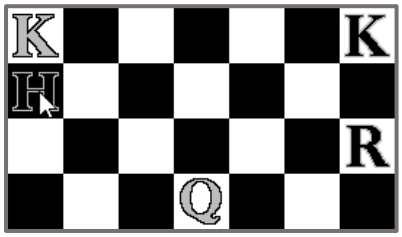


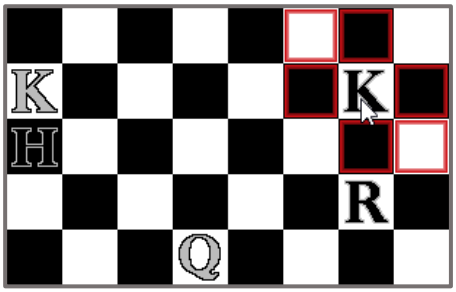


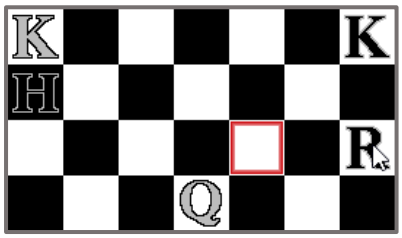
On the left is another configuration. Black is in check by the white queen, and it is



black's turn (white is not in check; hawks move two or three spaces in any direction, but not one). Since black is in check, the only legal moves are ones that will take black out of check. For the hawk, there are no moves that will remove check, so there should be no moves shown. The rook could move two squares to the left to block the path of the queen, but nowhere else. The king itself could move anywhere except on the line formed by it and the queen to get out of check. The results of clicking each of these pieces can be seen below.







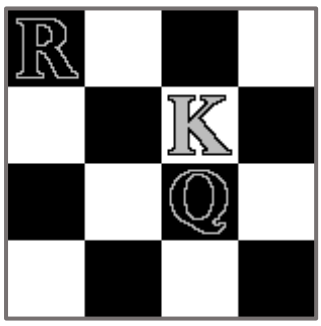
However, currently as a part of the move trialling process, piece capturing is not considered. This is because I have to undo each move I try ty evaluate check, but I have not currently implemented any way to undo a piece capture, so this will be the next thing I will do. Later on, I will implement a full move history with undoing of any number of moves, but right now I just need to undo by one move.

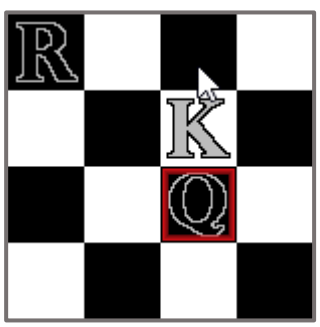
There will be a variable called `lastMove` which is part of the `Chess` class. This will have a default value of null, but whenever a piece is captured, it will hold a copy of the piece that was captured, so that it can be put back into the game if the move is undone. I will then update `Piece.move` to use this value appropriately, and `calculateMovement` to be able to reset this value of it was used.

```
public void move(Square s) {
    Piece p = Chess.pieces.Find(q => q.square == s);
    if (p != null) {
        Chess.pieces.Remove(p);
        Chess.lastMove = p;
    }
    square = s;
}
```

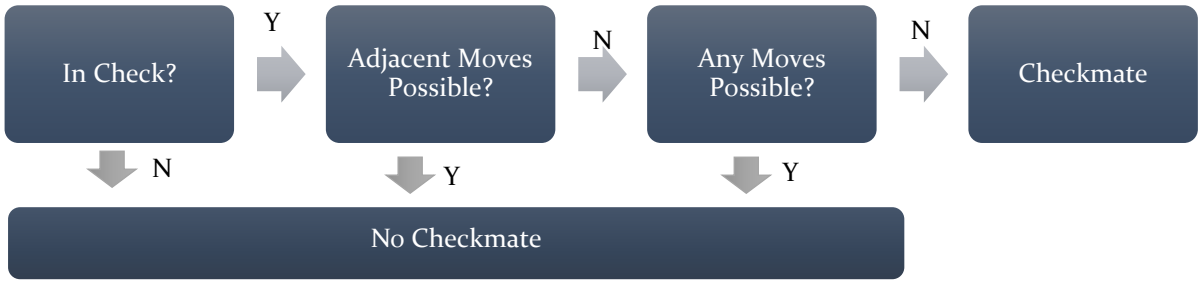
```
move(original);
if (Chess.lastMove != null) { Chess.pieces.Add(Chess.lastMove); Chess.lastMove = null; }
```

On the left is a scenario. With the previous code, there would be no viable moves for the king. With the new code, the expected result is that capturing the queen is an available move, which would remove the king from check. As can be seen, this is exactly what happens, which indicates the code works correctly.





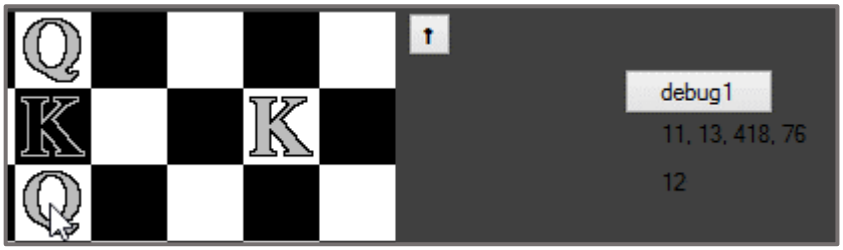
With this new infrastructure for evaluating check and calculating moves, checking for checkmate is now a lot simpler. The new process can be represented by this diagram:



This means `evaluateCheck` will look like this:

```
public bool evaluateCheckMate(PieceColour c) {
    Piece king = pieces.Find(p => p.type == PieceType.KING && p.colour == c);
    if (king.calculateMovement(false).Count() != 0) return false;
    var playerPieces = from p in pieces where p.colour == c select p;
    foreach (Piece p in playerPieces) { if (p.calculateMovement(false).Count() != 0) return false; }
    return true;
}
```

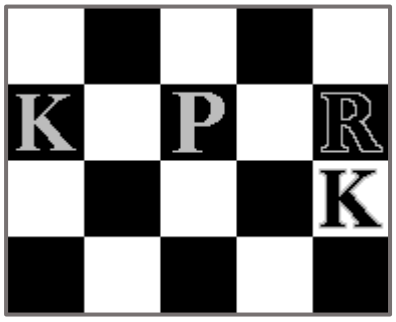
To the left is an initial configuration. It is white's turn, and the queen below the black king moves to the position indicated in the image on the right. This is of course checkmate. This means the `WIN` flag (`0x08`) should be set for the player that has won after this turn is complete. Looking to the right, the game state is `12`, which is `WIN 0x08 + CHECK 0x04`. The lack of `COLOUR 0x01` signifies this is referring to white. Therefore, state `12` represents white having won the game, which is correct.

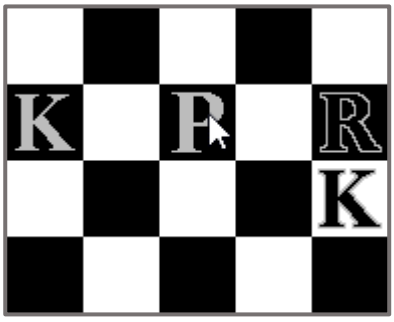


I will now do some movement tests with the new calculations to ensure it is working properly. If they are successful, this would mean the game is playable as a chess game with two human players.

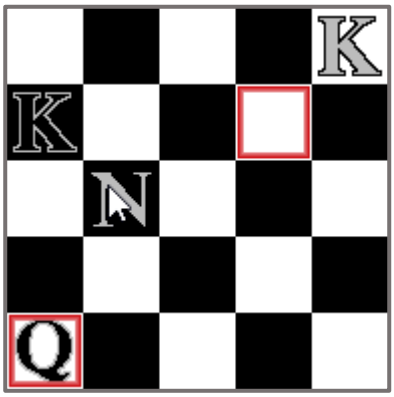
Updated Piece Movement Tests

* The white pawn will be clicked.
* No squares should become highlighted. Any move by the pawn would put the white king in check.
* The outcome was as expected.

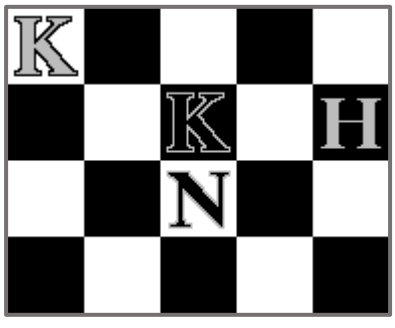


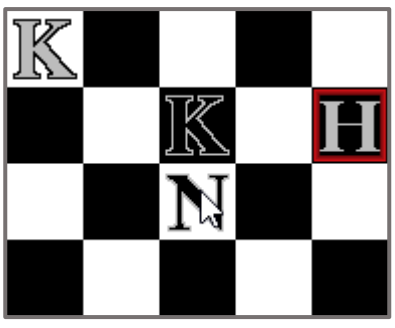


* The white knight will be clicked.
* The black queen and the square to the bottom left of the white king should become highlighted. Other moves would not remove the white king from check.
* The outcome was as expected.

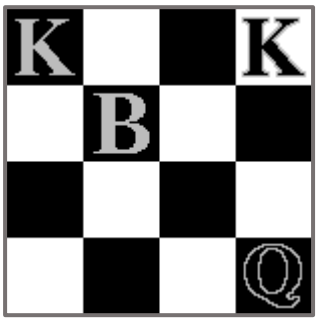


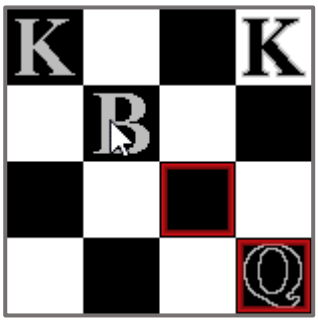
* The black knight will be clicked.
* The white hawk should become highlighted. All other moves would not remove the black king from check.
* The outcome was as expected.





- The white bishop will be clicked.
- The two squares to the lower right should become highlighted. The other squares would put the white king in check.
- The outcome was as expected.

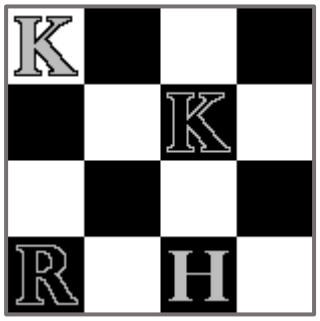


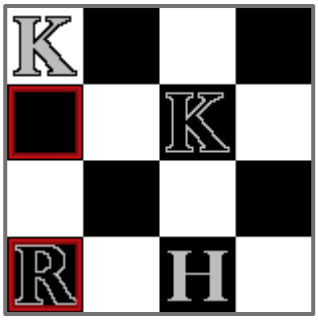


- The black rook will be clicked.
- One square to the right and two squares to the left should become highlighted. The other squares would put the black king in check.

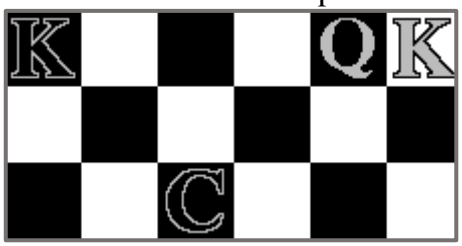
- The outcome was as expected.

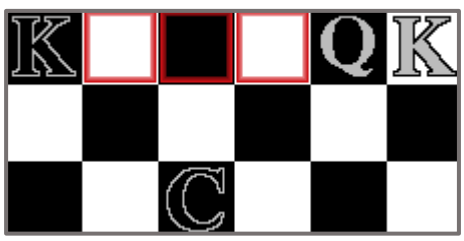
- The white hawk will be clicked.
- The rook and the square below the white king should become highlighted.
- The outcome was as expected.



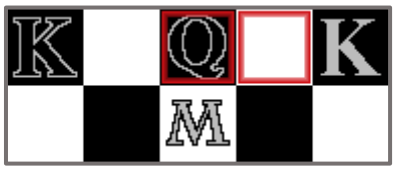


- The black chancellor will be clicked.
- The three squares between the black king and the white queen should become highlighted.
- The outcome was as expected.

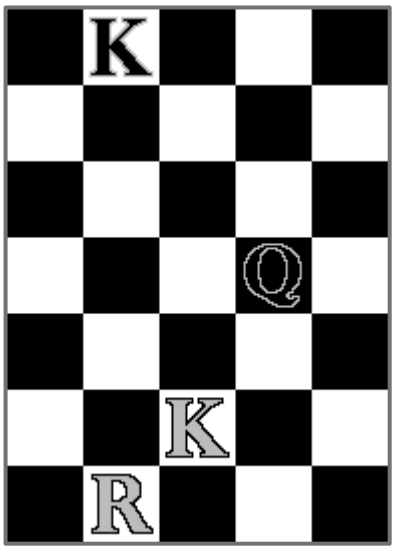
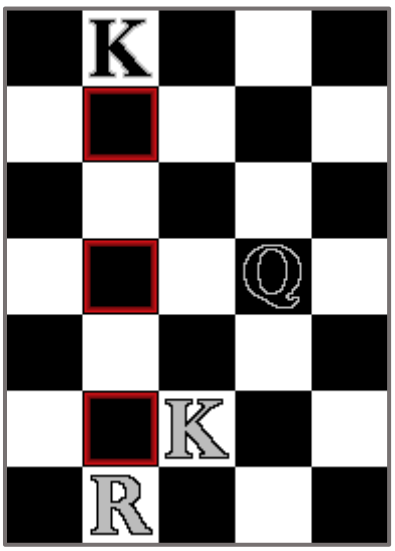




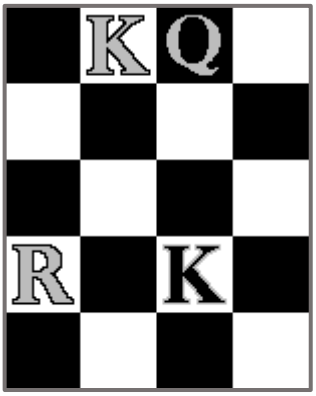
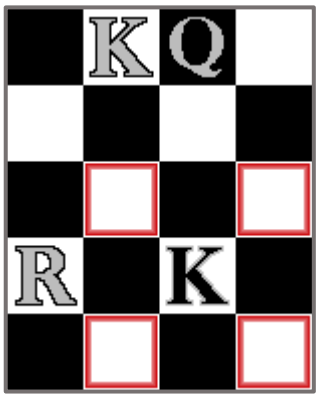
- The white mann will be clicked.
- The black queen and the square to the right of it should become highlighted.
- The outcome was as expected.

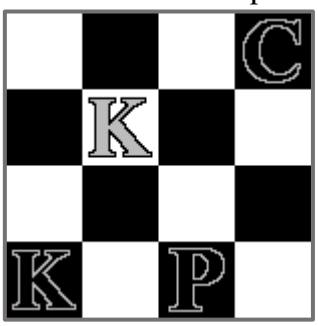
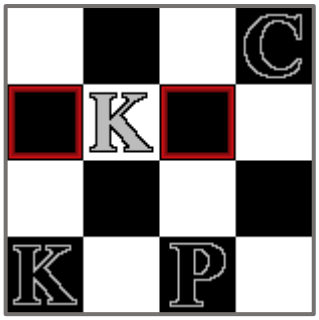
- The black queen will be clicked.
- The square two to the left of the queen, and the two squares which two squares above and below this square should become highlighted.
- The outcome was as expected.

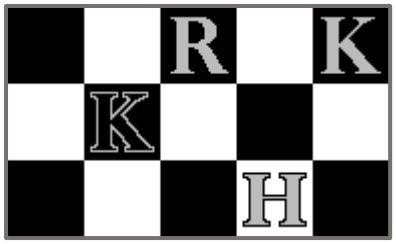
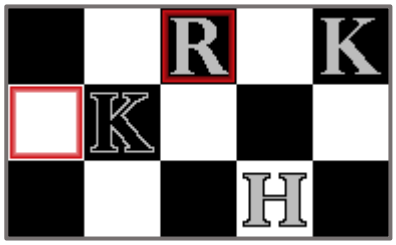
- The black king will be clicked.
- The 4 diagonal squares around the king should become highlighted. The others would put the king in check.
- The outcome was as expected.

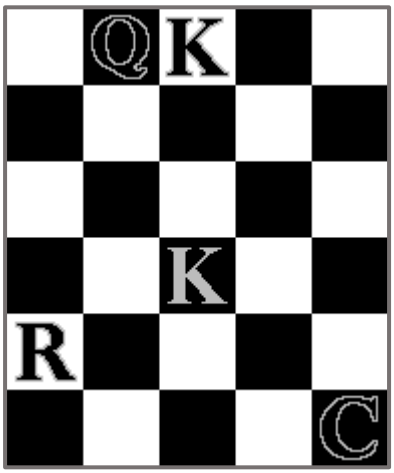
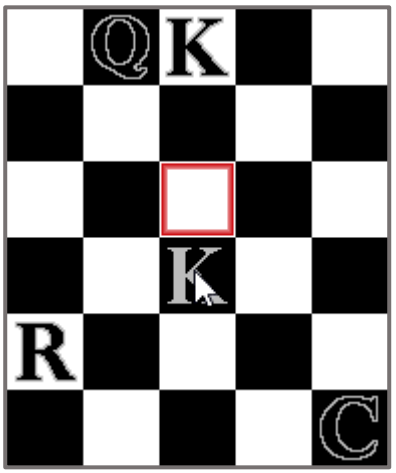
- The white king will be clicked.
- The squares to the left and right should become highlighted.
- The outcome was as expected.

- The black king will be clicked.
- The squares to the left and top right should become highlighted.
- The outcome was as expected

- The white king will be clicked.
- The square above the white king should become highlighted.
- The outcome was as expected.

I can conclude from these results that movement works when taking the possibility of check into account. This means the game is now in a state where it can be played fully by two human players.

Move History

The main feature that isn't directly gameplay for the game will be the move history. As mentioned in the design section, this is a list which will describe all moves that have happened in the game, written in the standard notation for infinite chess. As moves happen, they will be added to the list. I will want to be able to manage and edit the data of stored moves in a convenient way, so I will make `MoveHistory` a class which extends `TextBox`.

`MoveHistory` will store a list which contains each move in string form. It will also have two methods responsible for adding and removing moves from the list. The framework for this class looks like this:

```
public class MoveHistory : TextBox
{
    public List<string> moves { get; private set; }

    public void addMove(string m) {
        moves.Add(m);
        Lines = moves.ToArray();
    }

    public string undoMove() {
        string a = moves.Last();
        moves.Remove(a);
        Lines = moves.ToArray();
        return a;
    }
}
```

The way I want this to work is that in `handleTurn`, instead of calling `Piece.move` directly, I will call `history.addMove`, which will both call `Piece.move` and handle updating the history display. An important point is that `calculateMovement` will continue to use `Piece.move` as opposed to `history.addMove` because I do not want every possible move being added to the history every time a player clicks on a piece.

`addMove` will need to take in the piece that is moving and the square it is moving to as arguments. It will then put the information needed for the history (first letter of piece type, square it's on etc.) into a string. The piece will be moved, and the string to be written to the history will be completed based on whether there was a piece in the square that was just moved to. I could use `checkSquareForPiece` to determine if there was a piece in the `Square` that was moved to, but this seems rather unnecessary since `Piece.move` already does this. A better solution is to use an `out` parameter in `Piece.move`. This means that I can have the option to use a return value from the function, but still keep the type `void` so I am not forced to use the function as a value. The out parameter will return a piece, which will be `null` if there was no piece on the square that was moved to or will contain the information for the piece if there was one.

This new function looks like this:

```
public void move(Square s, out Piece pOut) {
    Piece p = Chess.pieces.Find(q => q.square == s);
    pOut = p;
    if (p != null) {
        Chess.pieces.Remove(p);
        Chess.lastMove = p;
    }
    square = s;
}
```

And I can now use this parameter in the history code like this:

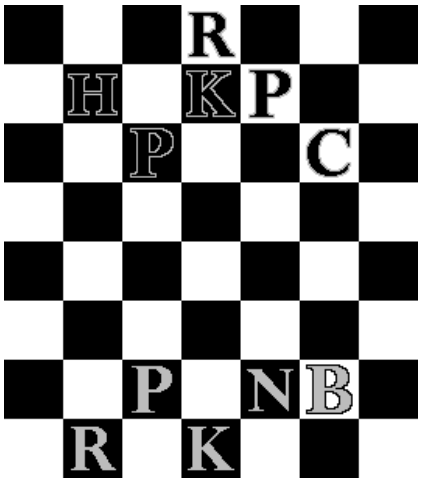
```
public void addMove(Piece p, Square s) {
    string[] data = p.ToString().Split(',');
    string moveText = $"{data[0].Substring(0,1)}({data[2]},{data[3]})";
    p.move(s, out Piece pOut);
    if (pOut != null) {
        data = pOut.ToString().Split(',');
        moveText += $"x{data[0].Substring(0,1)}({data[2]},{data[3]})";
    }
    else {
        moveText += $"-({s.indexX},{s.indexY})";
    }
    moves.Add(moveText);
    Lines = moves.ToArray();
}
```

This code will add moves to the history which will occur. The format these are in is described in the Game Design section, but the basic idea is to print the first letter of the type of piece that moved, then it's starting index, then a `x` if it captured something and a `-` if not, followed by the first letter of the piece captured (if there was one), and finally the square that was moved to. Here, I create an array called `data` which just takes the result of the method `p.ToString()` and splits it into an array based on where any commas are in the string. `p.ToString()` returns the type, colour, and square of the piece (using `Square.toString()`, which in turn returns the indexes and coordinates of a square). These two functions can be seen below.

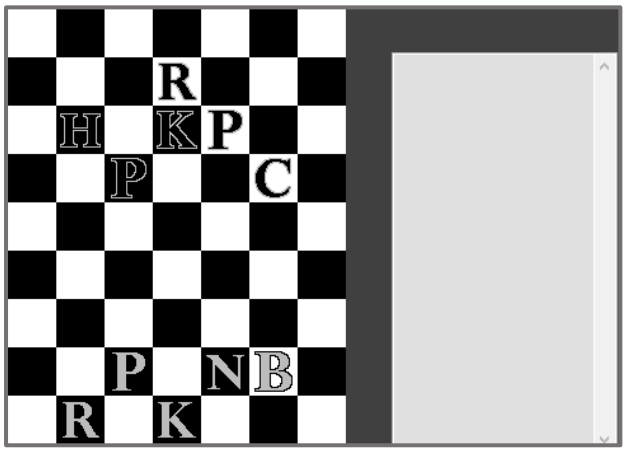
```
public override string ToString() => $"{type},{colour},{square.ToString()}";
```

```
public override string ToString() =>
    $"{indexX.ToString()},{indexY.ToString()},{X.ToString()},{Y.ToString()}";
```

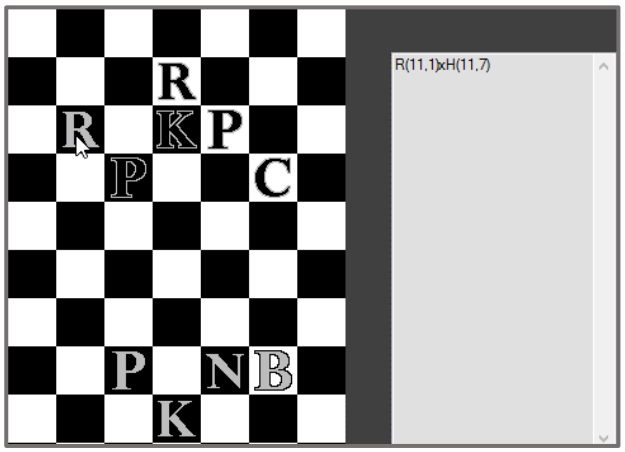
Now to test out this iteration, let's start with the scenario seen on the right. White of course goes first. I will then execute the following moves:



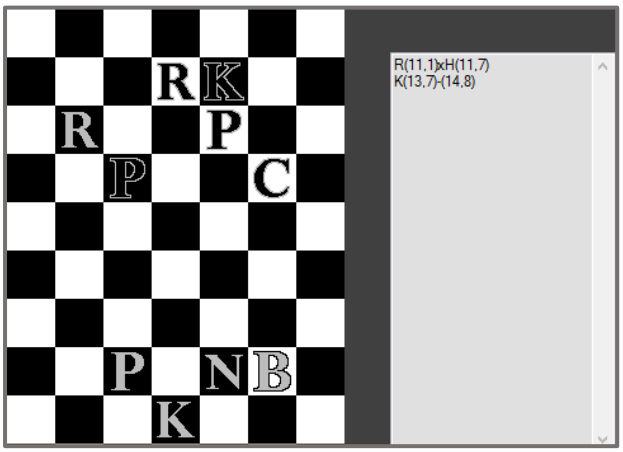
1. The white rook captures the black hawk.
2. The black king moves behind the right black pawn.
3. The white rook moves to the black king's previous location.
4. The black chancellor captures the white rook.
5. The white king moves to the right.
6. The black chancellor moves between the white pawn and knight.
7. The white bishop moves forward and to the right.
8. The black rook moves two to the left.
9. The white bishop captures the black rook.



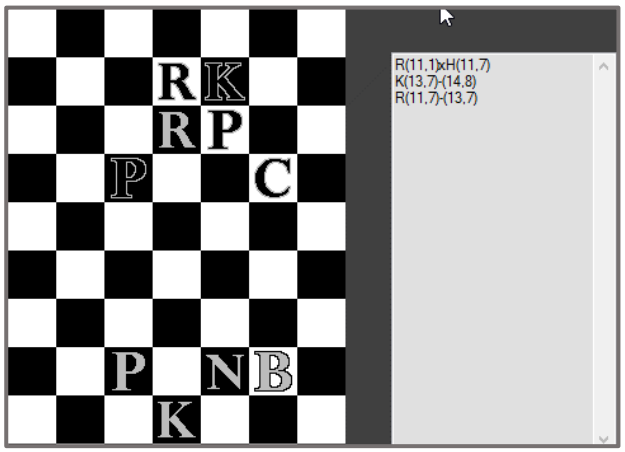
0



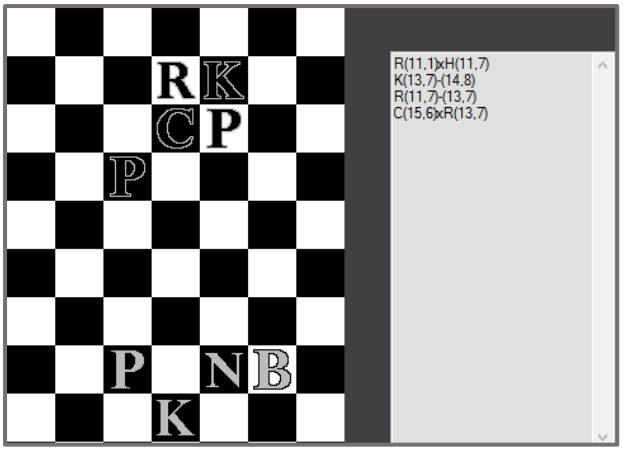
1



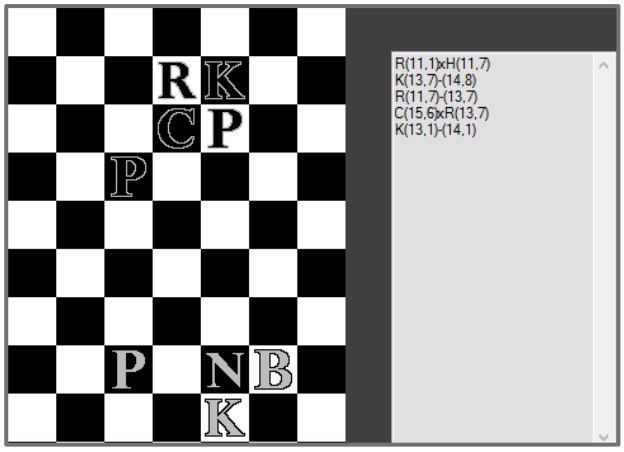
2



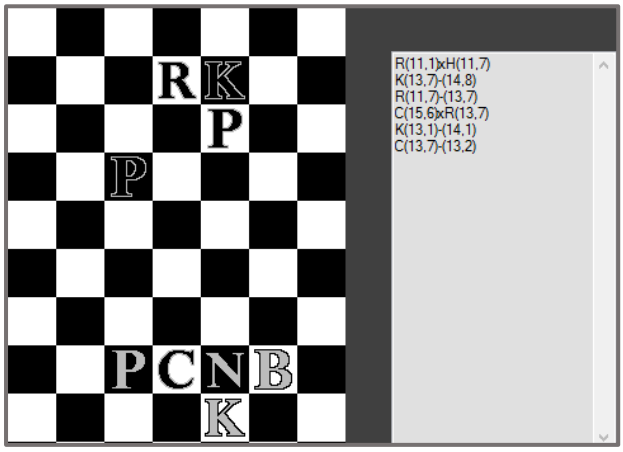
3



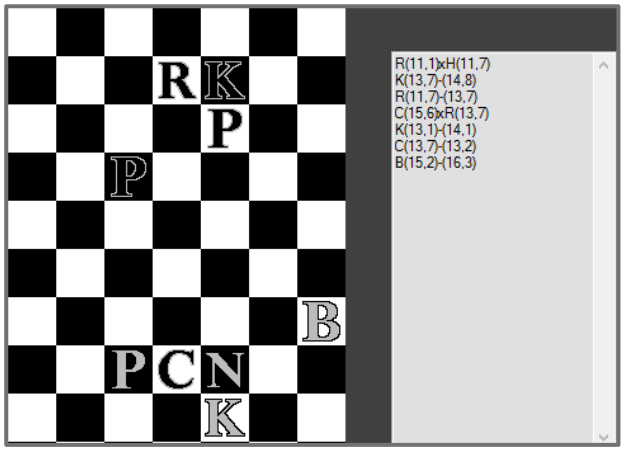
4



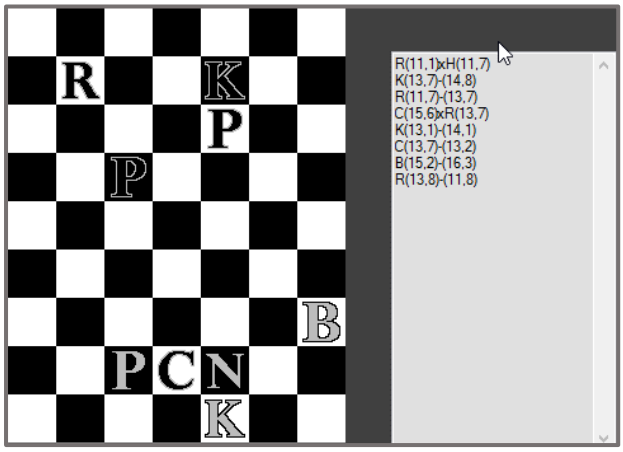
5



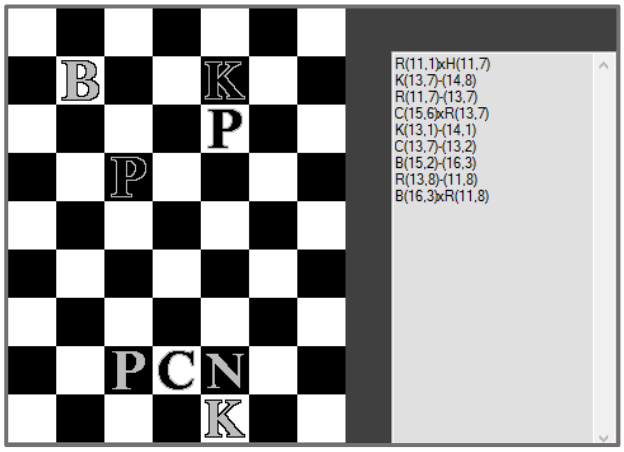
6



7



8



9

To the right in each screenshot is the move history at that point. It would appear that so far it is working correctly.

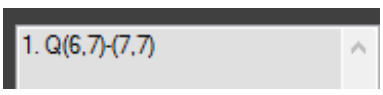
The format of the moves is not quite what I want. In chess, a 'turn' actually refers to a move by black and a move by white combined. For the history, I want one turn per line (white being in the right column and black being in the left). I also want numbers on each row so that it's easy to see what happened on a given turn. This is not too difficult to achieve; I will write a function, `updateMoves`, which will take `moves` and format it in the way I want, and then print that to the history. I will format them in the following way:

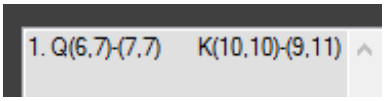
```
{Turn Number}. {White Move}      {Black Move}
```

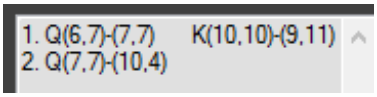
This will be done with the following code:

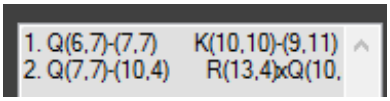
```
public void updateMoves() {
    List<string> result = new List<string>();
    for (int i = 0; i < moves.Count(); i += 2) {
        int lineNo = (i + 1) / 2;
        string line = $"{lineNo+1}. {moves[i]}";
        if (moves.Count() != i+1) line += $"      {moves[i+1]}";
        result.Add(line);
    }
    Lines = result.ToArray();
}
```

Every time this is done, I must check if we are on a black or white turn. Since a white move will be `moves[i]`, and black moves will be `moves[i+1]`, if black has not yet moved, `moves[i+1]` will not exist and an exception will be thrown if there is an attempt to access it. The result can be seen below.

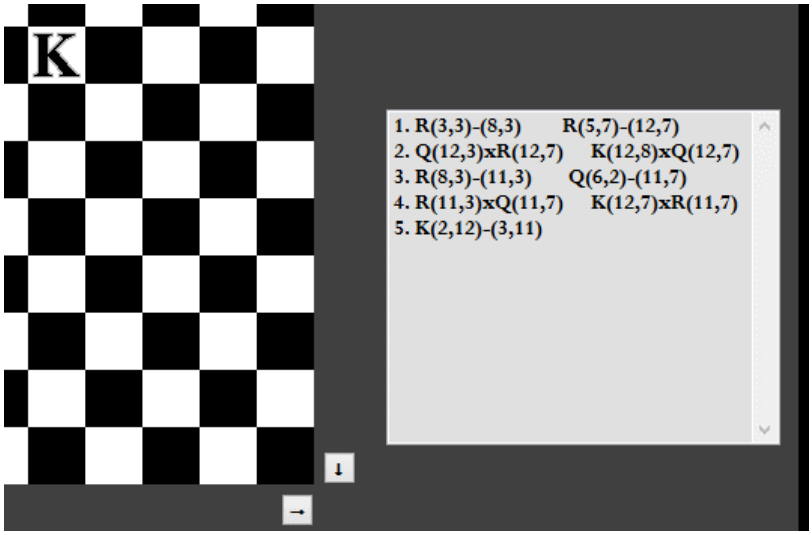








The formatting of the text is better, but there is a bit of a problem with it being longer than the textbox itself. My solution is to make the window bigger, so I can increase the size of the textbox. The bottom screenshot shows this new wider text box, and I also changed the font of the box while I was at it.

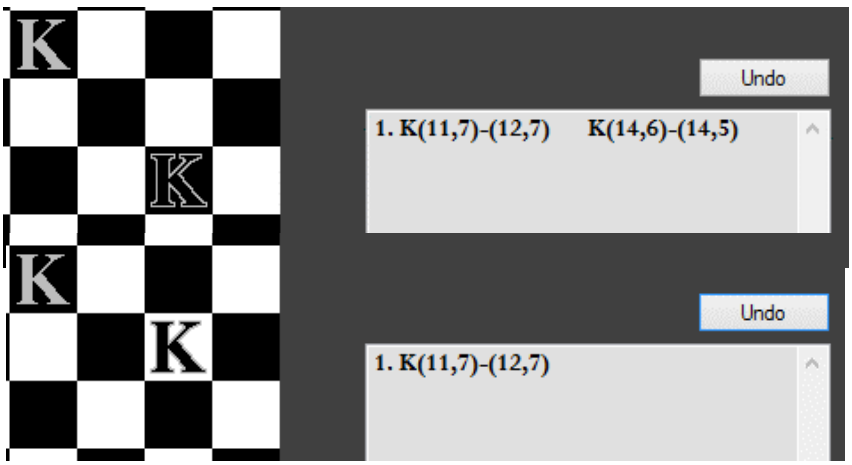


Undoing Moves

The next thing to do is add the ability to undo moves using this history. This should not be too difficult, as all the information needed to undo a move will be in the string representation of the last move. Initially, I will write some code that will revert moves, but not add back any captured pieces.

```
public void undoMove() {
    if (moves.Count() == 0) return;
    string lastMove = moves.Last();
    state ^= GameState.COLOUR;
    moves.Remove(lastMove);
    MatchCollection matchSquares = Regex.Matches(lastMove, "-?\\d+,-?\\d+");
    MatchCollection matchPieces = Regex.Matches(lastMove, "[A-Z]");
    Square to = GameContainer.findSquareByIndex(
        int.Parse(matchSquares[1].Value.Split(',')[0]),
        int.Parse(matchSquares[1].Value.Split(',')[1])
        );
    Square from = GameContainer.findSquareByIndex(
        int.Parse(matchSquares[0].Value.Split(',')[0]),
        int.Parse(matchSquares[0].Value.Split(',')[1])
        );
    Piece p = pieces.Find(q => q.square == to);
    p.move(from, out Piece r);
    updateMoves();
}
```

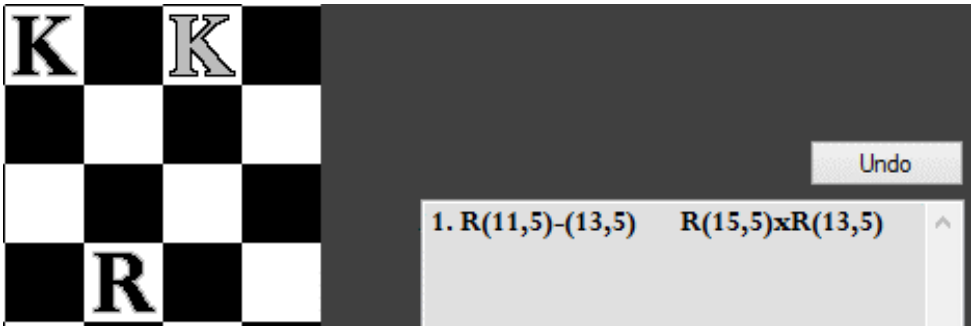
This code takes the last entry from `moves` and removes it, after saving it to a local string. I then use Regex to locate the information I need in the string, before using this to get a reference to the two Squares I need. I then find the piece which has the second square of the previous move, which will be the piece that just moved. This piece is moved back to its previous location, and the history is updated. Of course, when an undo happens, the colour state needs to be flipped because when a move is undone, the previous player will need to do another move. Below can be seen a test of this code; two moves were made and then one of them was undone. The black king returned to its previous spot as a result, which is the expected outcome.



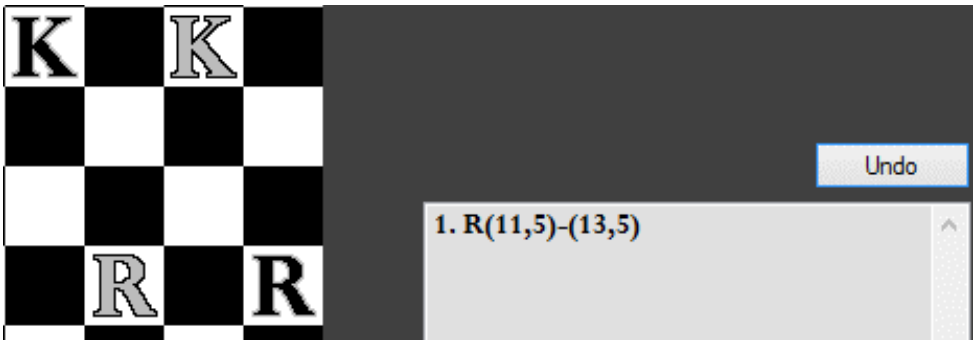
When a piece is captured in a move, the history for that move will contains an ‘x’. This makes it easy to determine whether I need to restore a captured piece when a move is undone. As before, all the information I need to do this is in the history; it is just a matter of parsing and using it.

```
if (lastMove.Contains("x")) {
    PieceType type = typeFromPrefix(matchPieces[1].Value);
    PieceColour colour = moves.Count() % 2 == 0 ? PieceColour.BLACK : PieceColour.WHITE;
    pieces.Add(new Piece(type, to, colour));
}
```

To test it out, here is a scenario, where a white rook has been captured by a black rook.



Pressing undo should move the black rook back to [15,5], and the white rook should return to the board at [13,5].



This suggests undoing moves is working correctly. I think the testing done in this section is sufficient to conclude that the history as a whole is working correctly, so I can call it done and move on to the next feature.

Miscellaneous Features

Before I continue, I want to implement a few features which did not fit under any of the previous headings or relied on one or more to be implemented. Some of these are aesthetic or quality of life changes, some are efficiency changes, and some are small but vital parts of the game.

First, during a turn pieces are clicked to display their movement (which involves calculating their movement, which is a fairly time-consuming process). When the user goes to click one of the squares that have been highlighted to move the piece, the piece's movement is calculated again to determine if they clicked on a square the piece can move to. There is no reason to calculate the movement a second time, when the movement could be stored in a local variable quite easily the first time round, which can then be used to determine if the user clicked a valid square.

```
public static List<Square> pieceMovingMoves = Square.emptyList();
```

And `handleTurn` will use this variable like this:

```
else {
    //colour of the other player
    var colour = state.HasFlag(GameState.COLOUR) ? PieceColour.WHITE : PieceColour.BLACK;
    if (pieceMovingMoves.Contains(s)) {
        c.history.addMove(pieceMoving, s);
        lastMove = null;
        if (evaluateCheck(colour)) {
            if (evaluateCheckMate(colour)) { state ^= (GameState.WIN | GameState.COLOUR); }
            state ^= GameState.CHECK;
        }
        state ^= (GameState.MOVE | GameState.COLOUR);
    }
    else state ^= GameState.MOVE;
    c.drawBoard();
    pieceMoving = null;
    pieceMovingMoves = Square.emptyList();
}
```

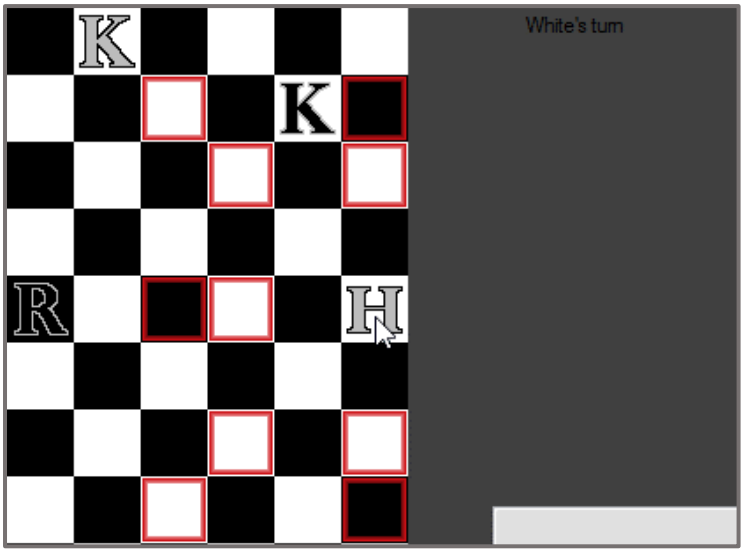
Everything seems to function the exact same as before, which is expected, so this code seems to be working.

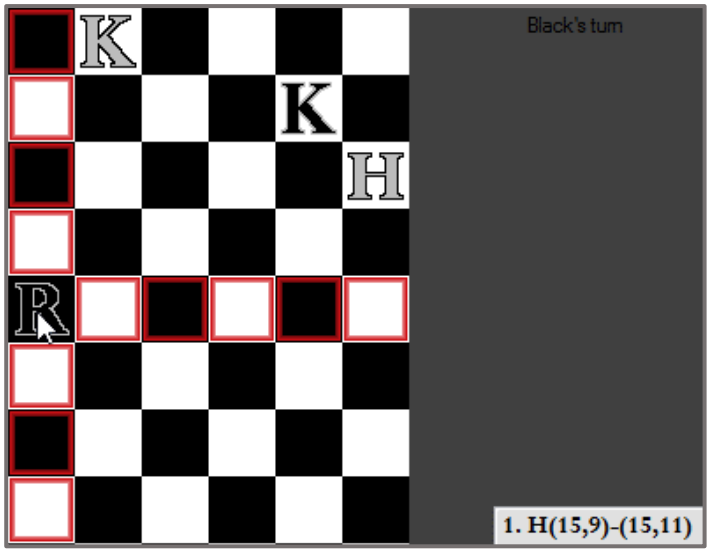
Next, I want to have a `GameState` parser which will take in a `GameState` and return a `string` which describes the state. This is something I will want to display to the user in the finished game, so it would be useful to do it now.

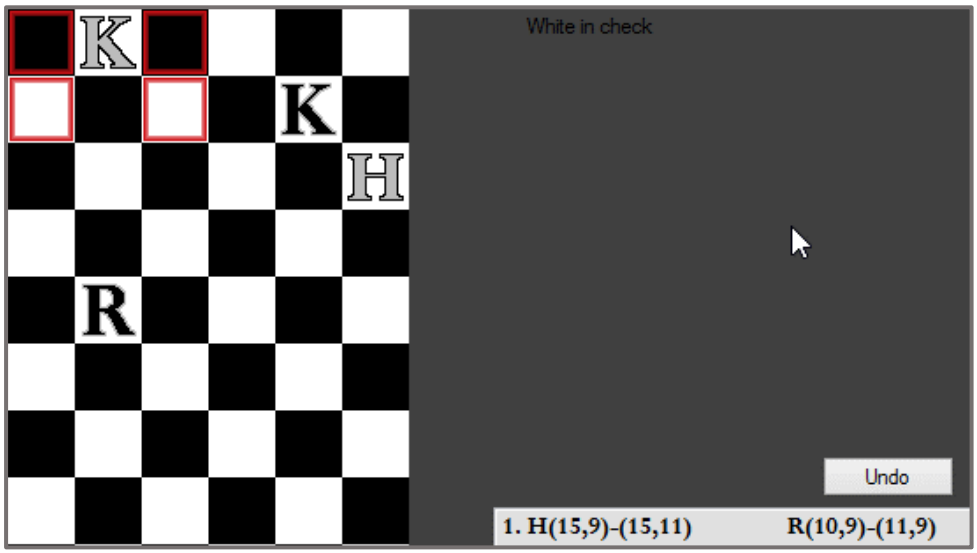
```
public static string parseState(GameState g) {
    string info = "'s turn";
    string colour = g.HasFlag((GameState)1) ? "Black" : "White";
    if (g.HasFlag((GameState)4)) { info = " in check"; }
    if (g.HasFlag((GameState)8)) { info = " has won"; }
    return colour + info;
}
```

```
c.debug3.Text = $"{parseState(state)}";
```

Testing it out:







I have not considered the possibility of stalemate so far. The most common way stalemate would be achieved in this game is to have all of one player's pieces have no available moves, but their king is not in check. Neither player wins since the king is not in check, but the game cannot continue. Since `evaluateCheckMate` evaluates whether any pieces of one colour have any valid moves, it is simple to add this as an outcome:

```
if (evaluateCheck(colour)) {
    if (evaluateCheckMate(colour)) { state ^= (GameState.WIN | GameState.COLOUR); }
    state ^= GameState.CHECK;
}
else if (evaluateCheckMate(colour)) { state ^= (GameState.STALE | GameState.COLOUR); }
```

And then adding this to the state parser:

```
if (g.HasFlag((GameState)16)) { colour = ""; info = "Stalemate"; }
```

In chess notation, which I am using in the move history, when a check or checkmate occurs, this is indicated by the addition of a symbol at the end of the move ('+' for check and '#' for checkmate). I will also add my own symbol, '~', to represent a stalemate. I need to add these into the history at the appropriate points in my game. However I cannot add them inside `history.addMoves`, since the check for check(mate) happens after the move has been made. To solve this, I will add a new function to `MoveHistory` which will append one of these symbols (based on a parameter passed into the function) to the last move that occurred:

```
public void addCheck(int state) {
    if (state < 0 || state > 3) return;
    string[] symbols = { "#", "+", "~"};
    moves[moves.Count()-1] += symbols[state];
    updateMoves();
}
```

And this function is used in the following way:

```
bool cm = evaluateCheckMate(colour);
if (evaluateCheck(colour)) {
    if (cm) {
        state ^= (GameState.WIN | GameState.COLOUR);
        c.history.addCheck(1);
    }
    else c.history.addCheck(0);
    state ^= GameState.CHECK;
}
else if (cm) {
    state ^= (GameState.STALE | GameState.COLOUR);
    c.history.addCheck(2);
}
state ^= (GameState.MOVE | GameState.COLOUR);
```

When moves are undone, a move which caused check or checkmate could be undone. If this happens I will need to reset the state too. This can be done easily by adding three extra lines to `undoMove()`:

```
if (lastMove.Contains('+')) state ^= (GameState)5;
if (lastMove.Contains('#')) state ^= (GameState)13;
if (lastMove.Contains('~')) state ^= (GameState)17;
```

This will reset all the appropriate states (and colours if necessary) so that the game can continue as expected if a game ending move is undone.

```
case 'i': {
        c.sUp.PerformClick();
        break;
    }
case 'j': {
        c.sLeft.PerformClick();
        break;
    }
case 'k': {
        c.sDown.PerformClick();
        break;
    }
case 'l': {
        c.sRight.PerformClick();
        break;
    }
```

I want to add the ability to scroll the board using the keyboard keys. This is simple enough to do, I will just extend the debug function I created earlier (the one which allows me to create pieces using keyboard keys) with some new keys, which will perform clicks on the scrolling buttons. To the left is the code that performs this task. They seem to work correctly, simply pressing the buttons confirms they work.

An important feature will be to load a board configuration from a config file at the start of the game. This will make it more customisable compared to if it was hard-coded. To store a board configuration in a file, I will use one line to represent one piece in the following format:

```
X,x,y,C
```

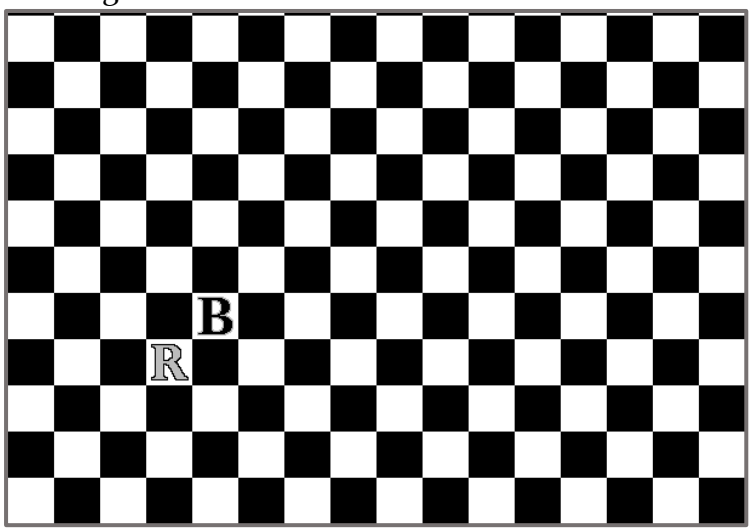
Where X is the prefix for the piece type, x and y represent the index of the square the piece is on, and C is the colour of the piece. For example:

```
R,3,8,W
```

represents a white rook that starts at [3,8]. Following is the code to implement this:

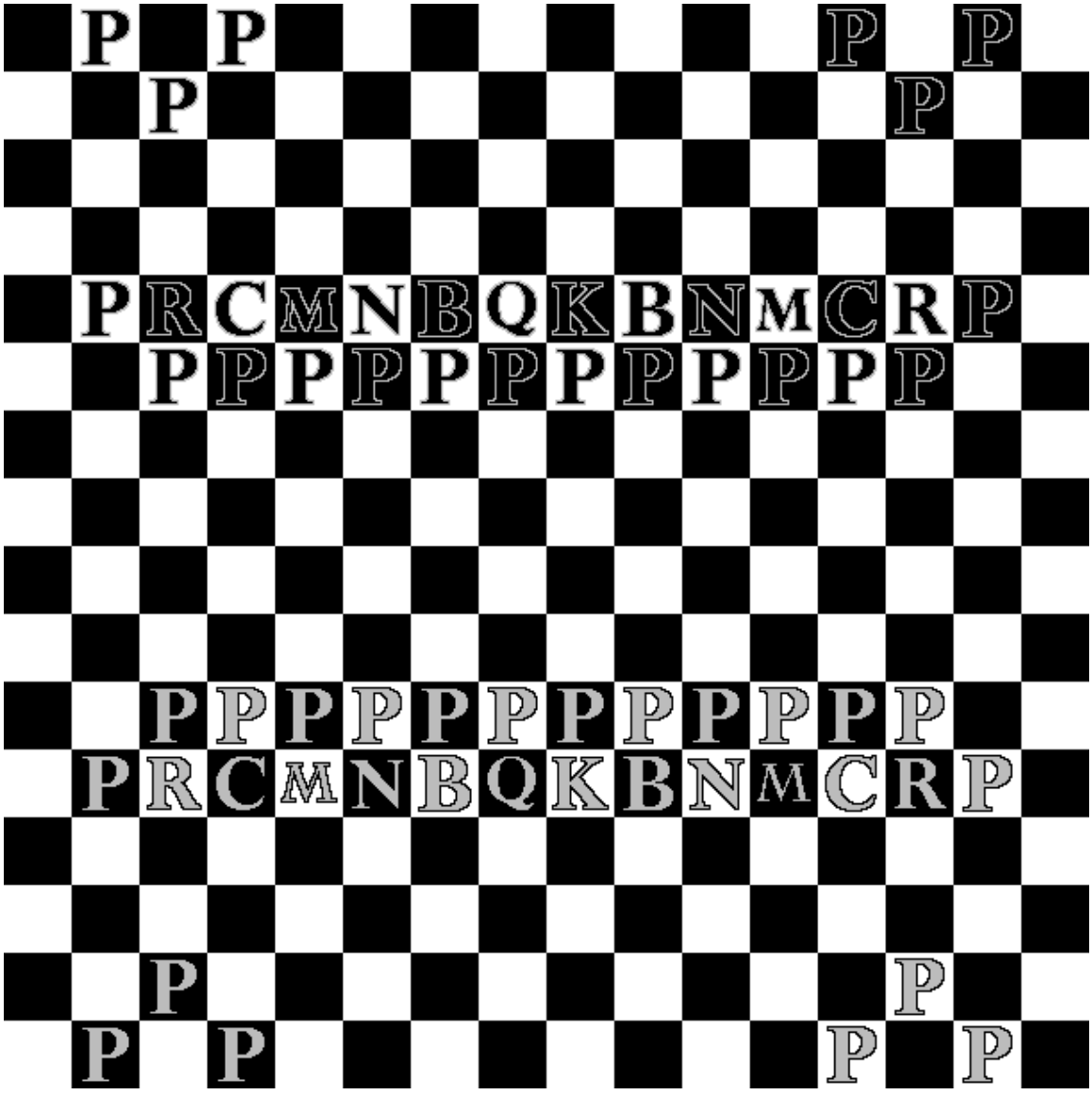
```
public static List<Piece> IntializePieces()
{
    List<Piece> pieces = new List<Piece>();
    string[] data = File.ReadAllLines("res/config/start.txt");
    foreach (string d in data) {
        string[] ds = d.Split(',');
        PieceColour colour = ds[3] == "W" ? PieceColour.WHITE : PieceColour.BLACK;
        pieces.Add(new Piece(
            Chess.typeFromPrefix(ds[0]),
            Chess.GameContainer.findSquareByIndex(int.Parse(ds[1]), int.Parse(ds[2])),
            colour));
    }
    return pieces;
}
```

I have created a sample configuration to test if this code works correctly, which can be seen along with the result below:




```
1    R,3,3,W
2    B,4,4,B
```

This looks correct to me, so I can fill in a more complete starting configuration.



After implementing this, I realise I had neglected the rule that allows pawns to move twice on their first move. In regular chess, I could just check if the pawn is on the second row from either the top or bottom of the board sine the only way a pawn can be in either of these rows is if it hasn't yet moved. However, the starting configuration for infinite chess contains pawns in many different rows. Instead, I will have a new attribute of `Piece` called `PawnData`:

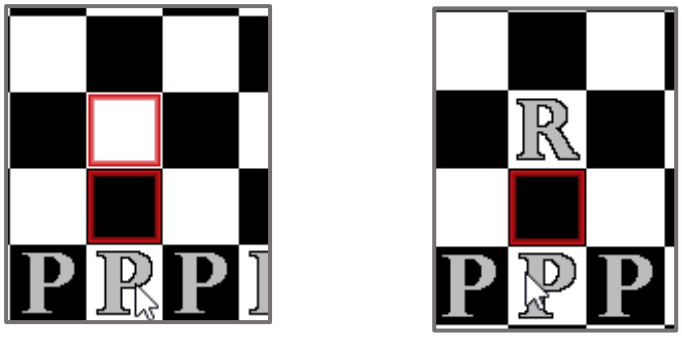
```
private bool PawnData = false;

public Piece(PieceType t, Square s, PieceColour c) {
    type = t; colour = c; square = s;
    icon = new Bitmap($"res/image/{c.ToString()}/{t.ToString()}.png");
    if (t == PieceType.PAWN) { PawnData = true; }
```

This is false for all pieces that are not pawns. When a pawn is created, it is set to true. This value is then used in the movement calculation for pawns;

```
if (PawnData) {
    int direction2 = colour == PieceColour.WHITE ? square.indexY + 2 : square.indexY - 2;
    Square attempt = Chess.GameContainer.findSquareByIndex(square.indexX, direction2);
    if (Chess.checkSquareForPiece(attempt, includeKings, colour) == 0)
        moves.Add(attempt);
}
```

```
public void move(Square s, out Piece pOut) {
    if (PawnData) PawnData = false;
```

When a pawn's movement is calculated, an additional square will be attempted if `PawnData` is true. If a pawn with this value set to true moves, it will be set to false.



However, a problem is that if moves are undone, this property will not be restored by the undoing function. The easiest way to solve this is to use a symbol which represents the first move by a pawn (I will choose to use '`'). Then I can simply check if a history entry contains this character, and if so, set `PawnData` back to true for that piece.

One problem I have noticed so far is that when all pieces are on the board, it takes a fairly long amount of time between clicking a piece to move it, and it actually moving. I would like to find out why this is, and if I can do anything about it.

To find out where the problem might be, I will set a breakpoint in `handleTurn`. I can then step through the code line by line, which is useful because visual studio tells me how long each line takes to execute. Most lines, such as the one below, take <1ms to execute:

```
else if (cm) {  ≤1ms elapsed
```

Evaluating checkmate takes 12ms, which is to be expected:

```
bool cm = evaluateCheckMate(colour);  ≤12ms elapsed
```

However, evaluating check takes a huge 559ms:

```
if (evaluateCheck(colour)) {  ≤559ms elapsed
```

This looks to be the source of the lag. I will take a look at this function and see if I can figure out why it is taking so long to execute:

```
public bool evaluateCheck(PieceColour c) {
    if (state.HasFlag(GameState.CHECK)) { state ^= GameState.CHECK; }
    Square king = pieces.Find(p => p.type == PieceType.KING && p.colour == c).square;
    for (int i = 0; i < pieces.Count(); i++) {
        Piece p = pieces[i];
        if (p.colour == c) continue;
        if (p.calculateMovement(true).Contains(king)) return true;
    }
    return false;
}
```

Stepping through again, I find this:

```
if (p.calculateMovement(true).Contains(king)) return true;  ≤8ms elapsed
```

Calculating the movement of a piece is taking about 8ms. This isn't so bad for a few pieces, but when all 76 pieces are on the board, it really adds up. There isn't really many ways I can speed up calculating movement of pieces, but what I can do is not calculate it at all if it is not necessary.

For example, there is absolutely no way a rook can be causing check if it does not share either a row or a column with the king in question. This does not mean that if it is sharing one, it is definitely causing check, but this is not important. The important thing is that if I can tell from a piece's coordinates whether it could cause check or not, I do not have to calculate its movement. This will be the case for the majority of pieces, so it should be much faster.

First, I will create some shorter names for the variables I will need to use for this:

```
short[] ps = new short[] { p.square.indexX, p.square.indexY };
short[] ks = new short[] { king.indexX, king.indexY };
```

Now I can use these for the rook, as explained above:

```
switch (p.type) {
    case (PieceType.ROOK): {
            if (ps[0] != ks[0] & ps[1] != ks[1]) continue;
            break;
```

Bishops will have a similar condition, but the bishop and king need to not be on the same diagonal. This equates to the difference between the X and Y index of each piece being different, which can be implemented like this:

```
case (PieceType.QUEEN): {
        if (ps[0] != ks[0] & ps[1] != ks[1] & ps[0] - ks[0] != ps[1] - ks[1])
            continue;
        break;
```

The queen will just be a combination of both of these rules (and the chancellor will use the rook rule as a component), but this line of thinking stops here. The other pieces do not have lines of movement, so how could I tell if they are in a situation where they cannot cause check?

Since the other pieces do not have linear movement, they must have a maximum range. This means that if the king is far enough away from the piece, the piece cannot be causing check. This is quite easy to implement; if the difference between the X indexes of both pieces or the Y indexes is greater than the range of the piece, I can skip over the piece. For the king and the mann, this range is one, for a pawn it is actually two because of the initial double move (which could cause check), for the knight it is two as well, and for the hawk it is 3. Below is the code for the hawk, but they are all implemented in exactly the same way, except for the value to check against changing.

```
case (PieceType.HAWK): {
        if (Math.Abs(ps[0] - ks[0]) > 3 |
            Math.Abs(ps[1] - ks[1]) > 3) continue;
        break;
    }
```

Testing this, movement is a lot faster now. Whereas before it took a few seconds to move a piece, the response now is basically instant. By setting up the breakpoint again, I can check how long the new function takes to run. Of course it will now vary depending on where the pieces are, but the best case scenario is when there are no pieces that could cause check, such as right at the start of the game:

```
if (evaluateCheck(colour)) {  ≤1ms elapsed
```

After creating 4 pieces in positions that deliberately fail these conditions (I would consider four possible pieces causing check at once at the start of the game a lot), I get this result:

```
if (evaluateCheck(colour)) {  ≤47ms elapsed
```

This suggests that the conditions are working as I expect, since it is calculating the movement for these four pieces. This is also still an order of magnitude faster than the original method, so this is a big improvement for the game.

Pawn Promotion

In regular chess, pawns can promote to other pieces when they reach the other end of the board. There is no "other end of the board" in infinite chess, but pawns actually can still promote. This happens when they reach the second starting row of enemy pieces (where the edges of the board would be in normal chess). This means white pawns will promote when they reach row 11, and black when they reach row 4.

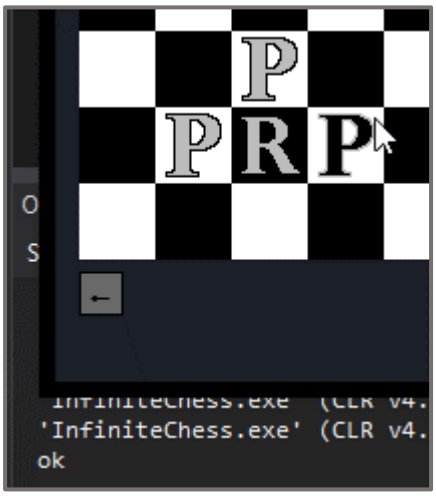
The way I want this to work is when a player moves their pawn to one of these rows, a window will appear which will prompt the user to select which piece to promote to. They will then make a selection and the pawn will be converted. In the history, a promotion of a pawn in the 13th column to a queen would look like this:

```
P(13,10)-(13,11)Q
```

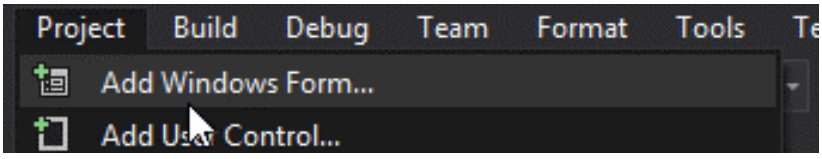
First, I need to check if a pawn of the appropriate colour has moved to one of those two rows:

```
if (p.type == PieceType.PAWN) {
    if (p.square.indexY == 11 && p.colour == PieceColour.WHITE
        || p.square.indexY == 4 && p.colour == PieceColour.BLACK) {
        Debug.WriteLine("ok");
    }
}
```

Testing it out, "ok" is printed to the debug console when I move a black pawn to row 4. The same also happens when a while pawn is moved to row 11. This does not happen when any other piece type is moved to rows 4 or 11.



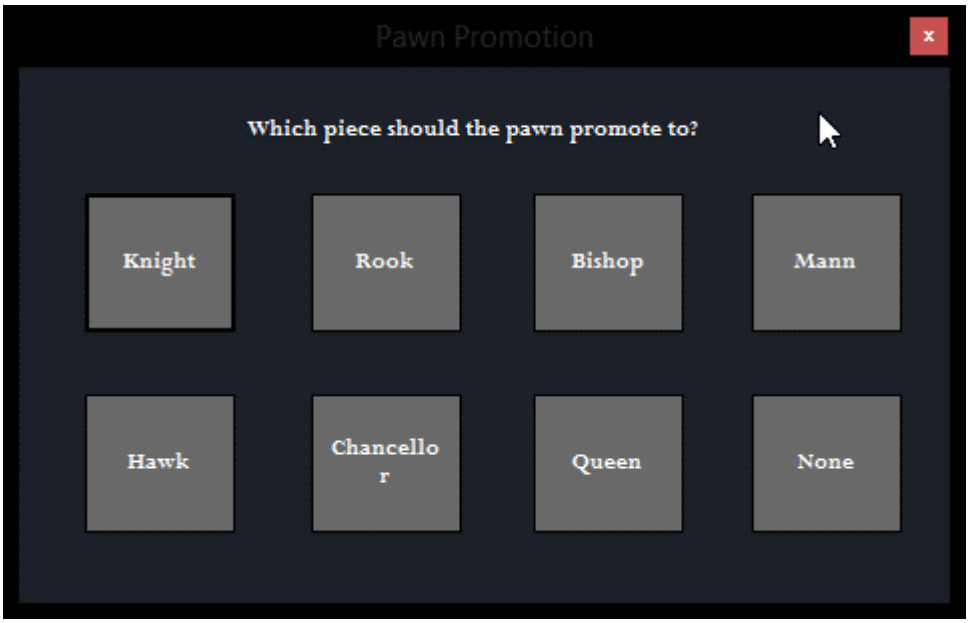
Now I need to create a form to show so that the user can pick a piece:



This creates a new empty form, which I will add an attribute to which will store the choice of the selection, called `choice`:

```
namespace InfiniteChess
{
    public partial class Promote : Form
    {
        public PieceType choice;

        public Promote()
        {
            InitializeComponent();
        }
    }
}
```

I can populate this window with a few buttons and a label, and style it to match the main window:



I will add graphics for these buttons later, but for now they are just text. To call this window, I simply create an instance of the class, and then run it. I will, be running it as a dialog box, which means that the main window cannot be interacted with until this one closes:

```
if (p.type == PieceType.PAWN) {
    if (p.square.indexY == 11 && p.colour == PieceColour.WHITE
        || p.square.indexY == 4 && p.colour == PieceColour.BLACK) {
        Promote pForm = new Promote();
        pForm.ShowDialog();
    }
}
```

These buttons are named in the form `pX`, where X is the abbreviation for the piece that button represents. For example, the queen button is called `pQ`. This naming system allows me to easily figure out which piece the user wants without having to create a separate `OnClick` method for each one. I will create a method `promoteClick` which will be called by all buttons when pressed. I will get the name of the button that called the function (which is passed in as an argument), trim the 'p' from it, and then use `Chess.typeFromPrefix` to find the value of `PieceType` needed. The value of choice will then be set to this, and the form will be closed.

```
private void promoteClick(object sender, EventArgs e)
{
    Button b = sender as Button;
    choice = Chess.typeFromPrefix(b.Name.TrimStart('p'));
    Close();
}
```

Now back in the move function, I can access this choice from the form, and test it by writing it to the console. Here, I pressed pawn and chancellor to test it out.

```
Promote pForm = new Promote();
pForm.ShowDialog();
Debug.WriteLine(pForm.choice);
```

```
PAWN
CHANCELLOR
```

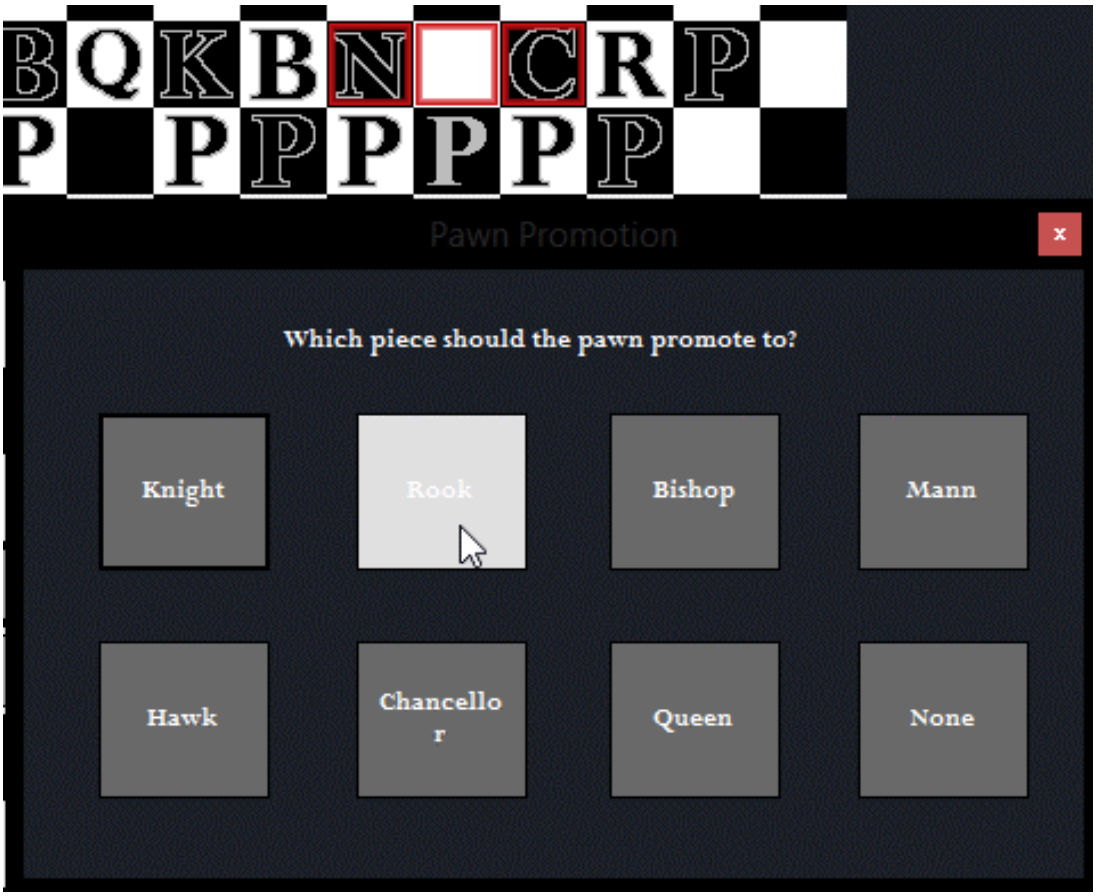
To actually change the type, I will write a new function in Piece to change the type of any piece to another:

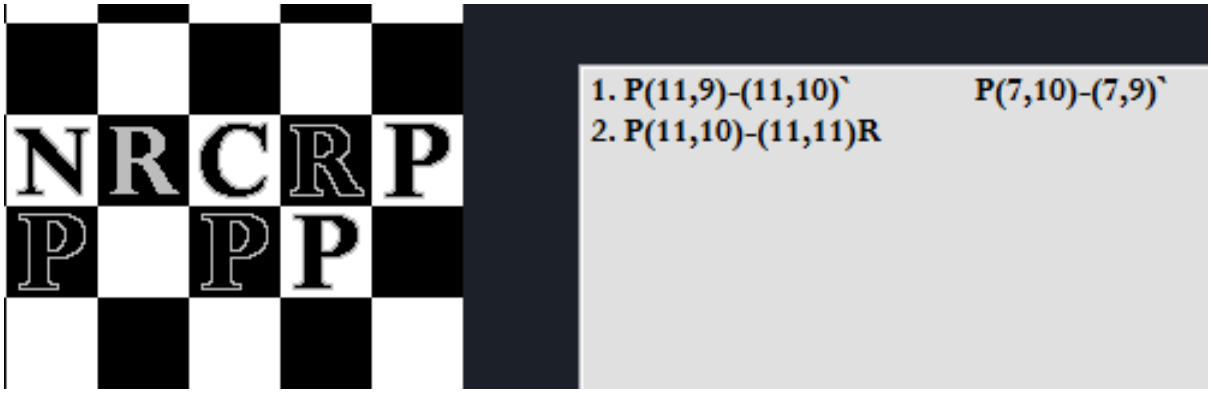
```
public void changeType(PieceType t) {
    type = t;
    icon = new Bitmap($"res/image/{colour.ToString()}/{type.ToString()}.png");
    PawnData = true;
}
```

PawnData is used to keep track of whether a pawn has made its first move or not. Since this does not apply to anything that isn't a pawn, I will use this attrribute in this case to signify that this piece is a promoted pawn. I can now change the type of the piece, and add the correct text to the history:

```
Promote pForm = new Promote();
pForm.ShowDialog();
p.changeType(pForm.choice);
moveText += pForm.choicePrefix;
```

Testing it out:

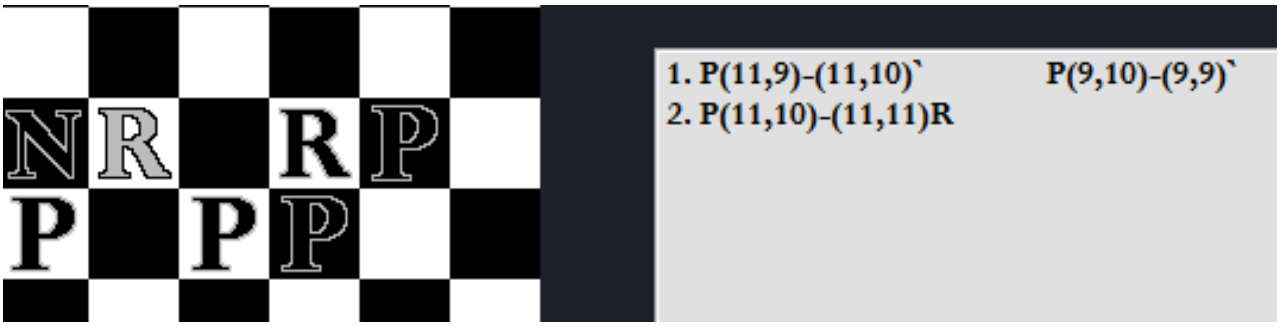




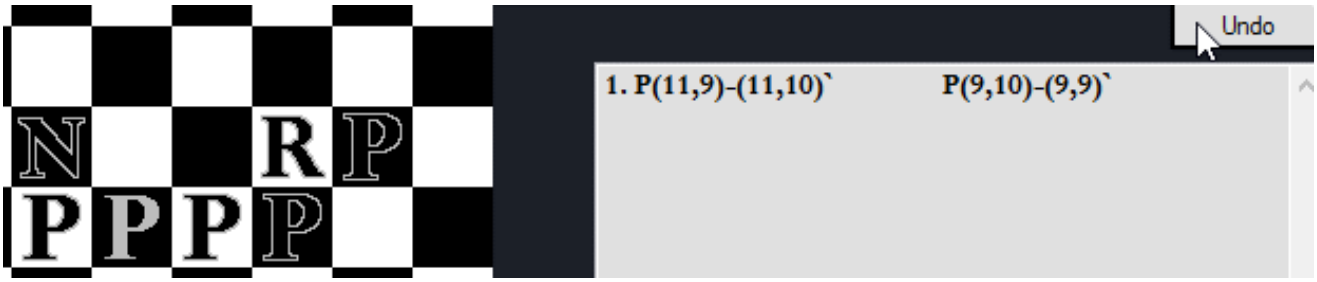
I need to be able to undo a promotion with the undo button. Previously, the only situation in which a move would contain more than one letter is if a piece was captured, but this is no longer the case. However, I can still tell what has happened in any given move because a capture always contains 'x', while a promotion does not. This means I can first check if there are two letters, and then if there is an `x` to decide what needs to be done to undo the move. For a promotion, all that needs to be done is set the `PieceType` back to pawn, and then set `PawnData` to `false`.

```
if (matchPieces.Count == 2) {
    if (lastMove.Contains("x")) {
        PieceType type = typeFromPrefix(matchPieces[1].Value);
        PieceColour colour = moves.Count() % 2 == 0 ? PieceColour.BLACK : PieceColour.WHITE;
        pieces.Add(new Piece(type, to, colour));
    }
    else {
        p.changeType(PieceType.PAWN);
        p.PawnData = false;
    }
}
```

In the situation above, I had promoted a white pawn to a rook on the third move:



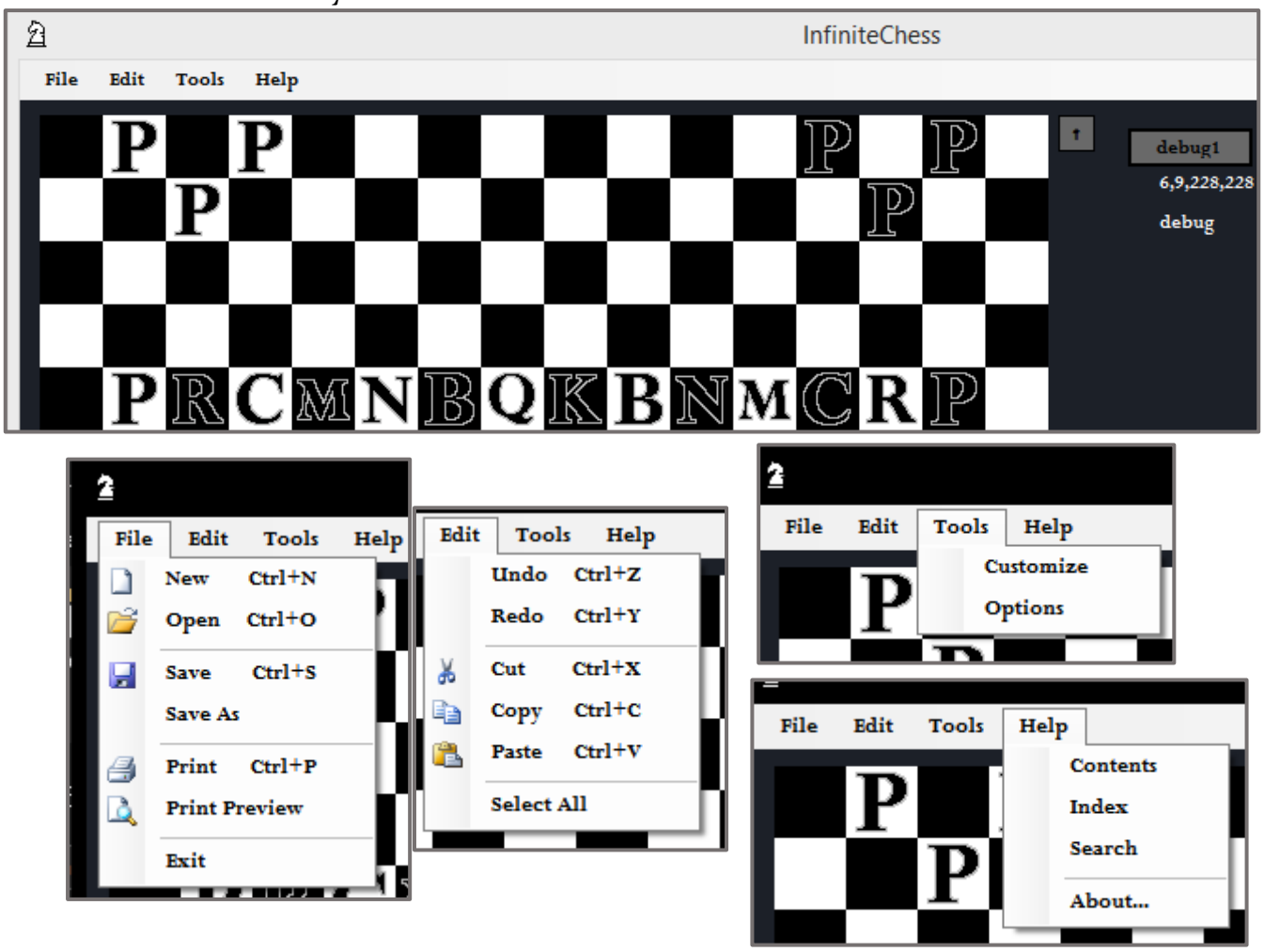
Undoing 1 move should cause the rook to move back one square, and then become a pawn.



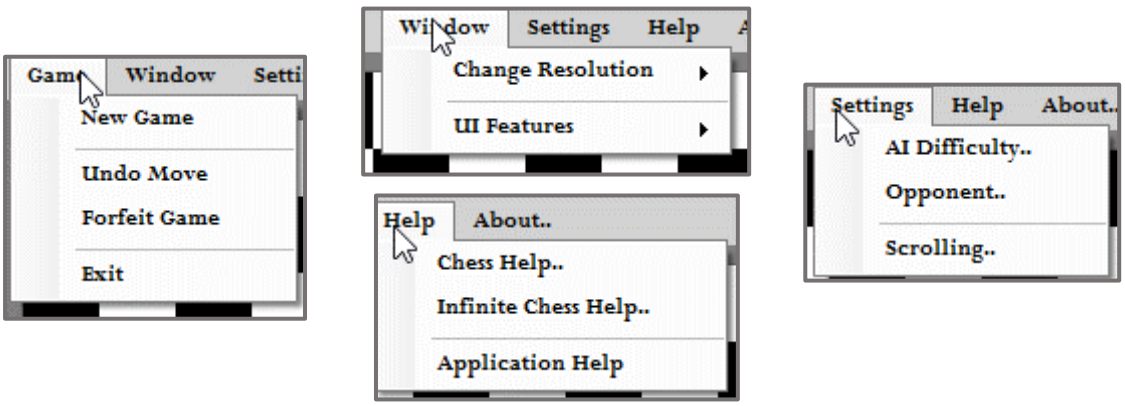
And as we can see, this is exactly what happens. I can conclude that pawn promotion works as expected.

Menu Bar

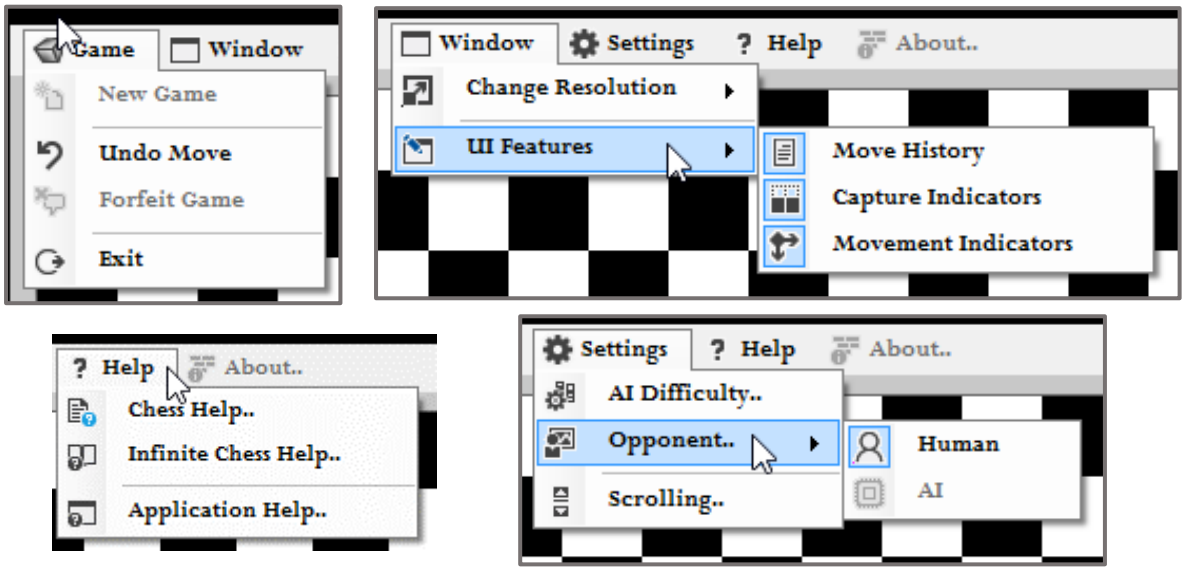
Next, I want to add a menu bar to the game. This will be the place where many of the settings and functions of the game will reside, as mentioned in the Window Design section. Adding one of these bars is not too difficult; visual studio provides them with some buttons already included:



However, none of these buttons actually do anything, and most of them have no application in my game. I will need to first redefine the available menus and buttons, and then write the functionality for each. Changing the buttons that appear on the menus is simple enough, as Visual Studio contains a GUI for this. I have changed them to be as they are specified in decomposition:



None of these do anything yet; some will be completed in this section, and some at a later time. Right now, they look a bit plain, since there are no icons or shortcuts anymore. Microsoft provides a library of icons[3] used in Visual Studio which are free to download and use, so I will make use of these to fill in some icons in order to give the menus a more professional look.



The functionality for each of these will need to be done individually, and some will be more complex than others. I will make a new file, `Menu.cs`, to hold all the methods related to menu buttons.

The two easiest ones are Undo Move and Exit, both of which are a single line of code:

```
private void menu_game_undo_Click(object sender, EventArgs e)
{
    undo.PerformClick();
}

private void menu_game_exit_Click(object sender, EventArgs e)
{
    Application.Exit();
}
```

Creating a new game is not too difficult either. Previously, the constructor for the form itself looked like this:

```
public Chess() {
    InitialiseVars();
    InitialiseBoard();
    InitialiseStyle();
    InitialiseFeatures();
    InitializeComponent();
}
```

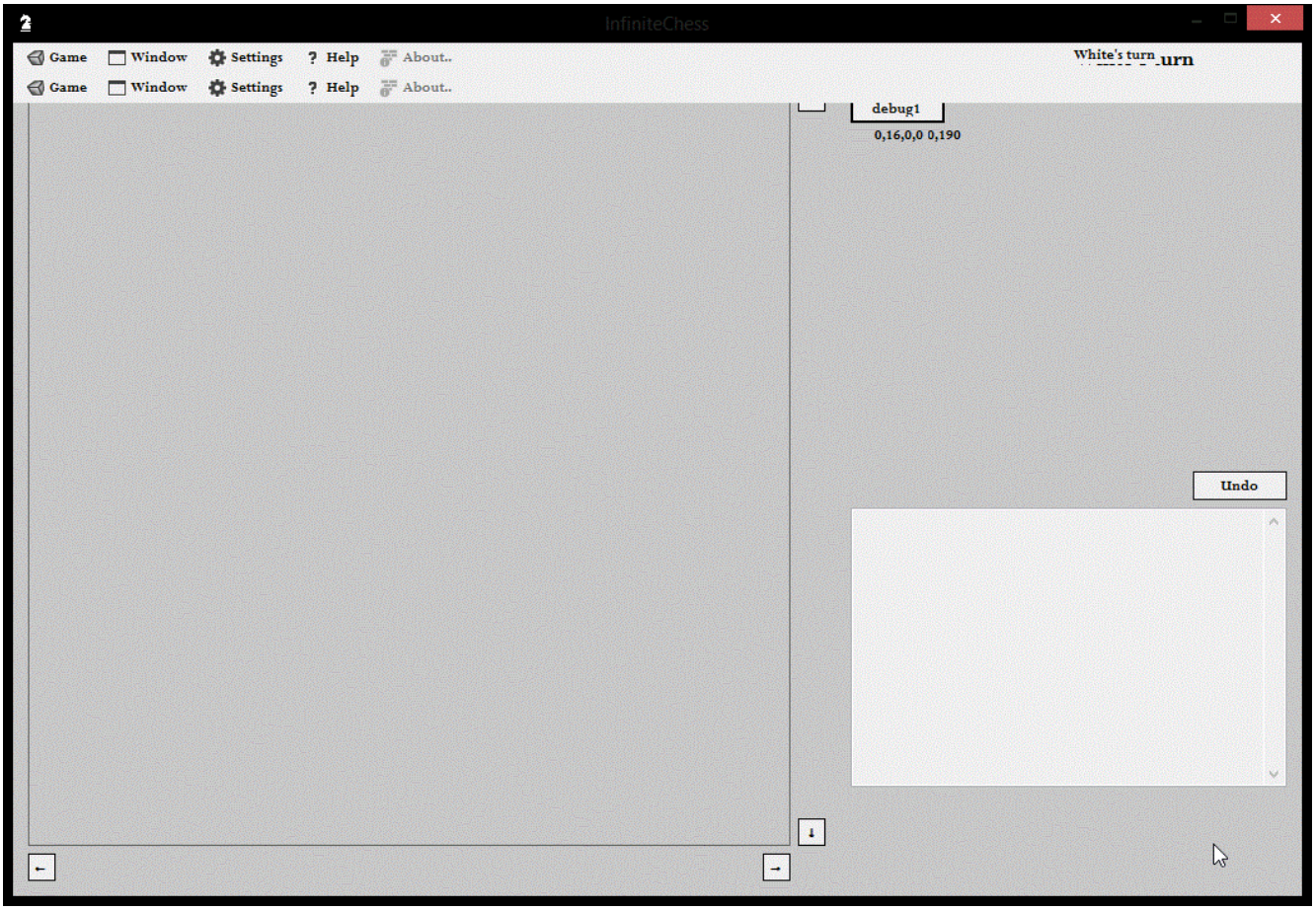
The first four functions are written by me, which set up different aspects of the game. For example, `InitialiseBoard` sets up the list of squares, `board` (as mentioned in Creating the Board). `InitialiseComponent` is generated by visual studio, and it adds all the controls to the form that I have designed, and then sets up all their properties, methods and events.

```
public Chess()
{
    Init();
}
#region init
public void Init()
{
    InitialiseVars();
    InitialiseBoard();
    InitialiseStyle();
    InitialiseFeatures();
    InitializeComponent();
}
```

To start a new game, all I would need to do is call these functions again (since these are the initialisation functions). I cannot call `Chess` because it is a constructor, not a method. This can be fixed by just creating a new method, `Init`, which will call all these functions, and will then itself be called in the constructor. This new setup can be seen to the left. This is then attached to the menu button:

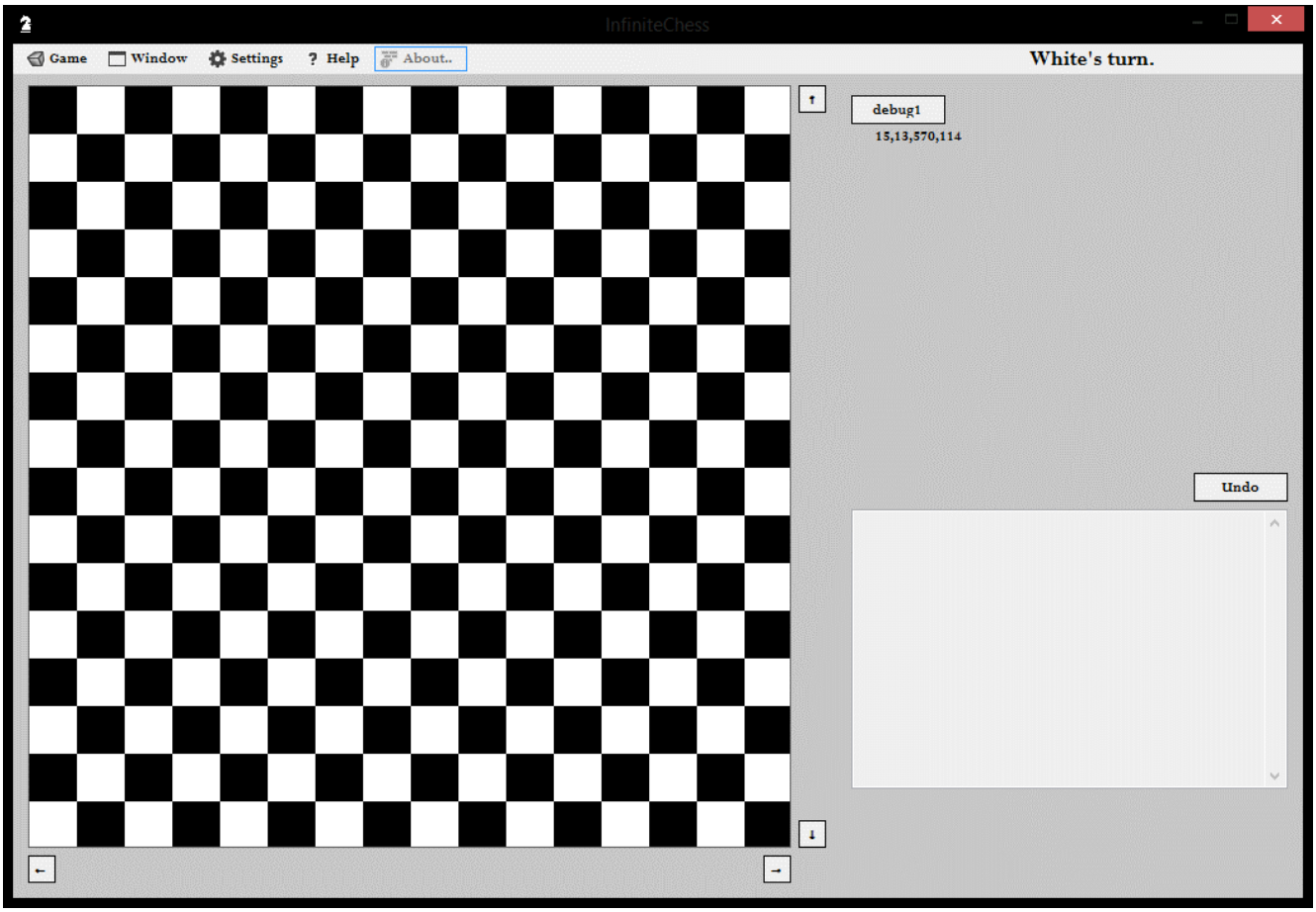
```
private void menu_game_new_Click(object sender, EventArgs e)
{
    Init();
}
```

And the following happens:



Another toolbar appeared, and nothing seems to be working. What has happened?

As it turns out, `InitialiseComponent` adds the controls to the forms collection, not set the forms collection to a certain list of controls. This is an important distinction, since the former means that calling it twice creates a duplicate of each control, while the latter would not. I do not want to call InitialiseComponent twice, so I will move it outside the new function and put it back in the form constructor. Now clicking the button again:

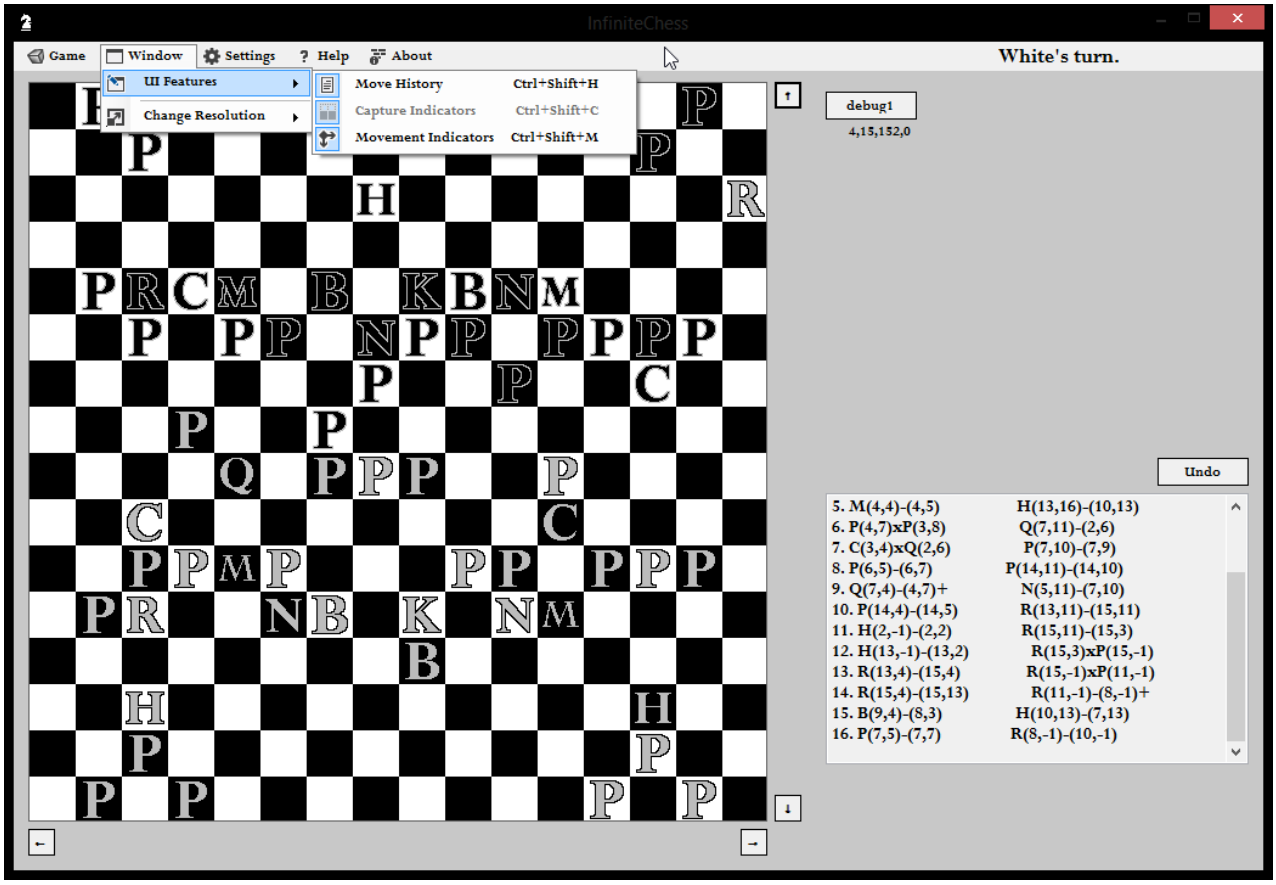


The game has been reset, there's no duplicate components, and everything still functions.

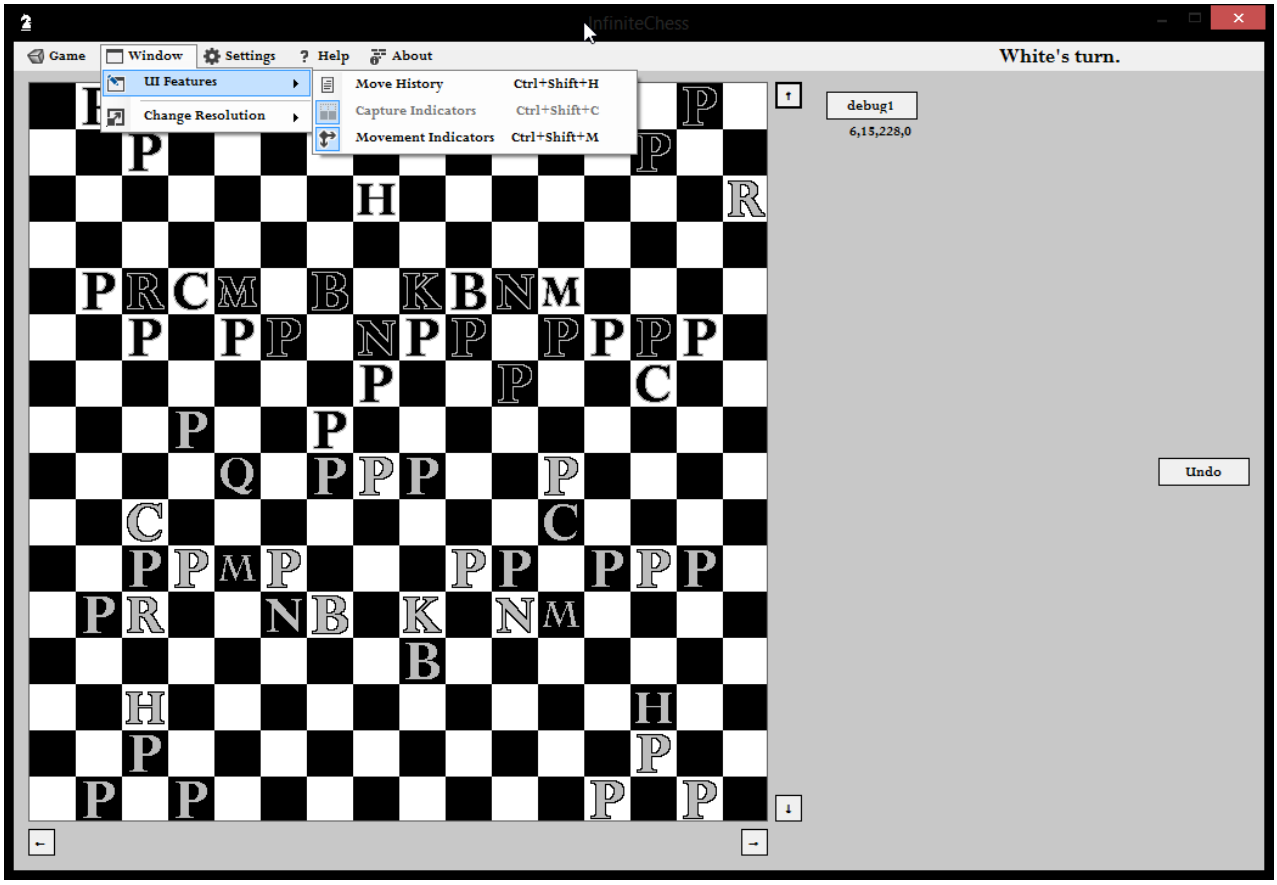
Next, hiding the history. This is also easy to do, the only thing I need to make sure of is that the option in the menu is highlighted when the history is enabled, and not highlighted when it is disabled.

```
private void menu_window_ui_hist_Click(object sender, EventArgs e)
{
    bool hidden = history.Visible;
    history.Visible = !hidden;
    menu_window_ui_hist.Checked = !hidden;
}
```

Enabled:



Disabled:

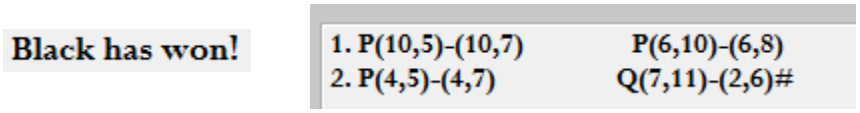


Next, forfeiting the game. This just involves setting the game state to win and to the opposite colour, and then adding # to the history to indicate a win.

```
private void menu_game_forfeit_Click(object sender, EventArgs e)
{
    state ^= ((GameState)9);
    history.addCheck(1);
    stateLabel.Text = $"{parseState(state)}";
}
```

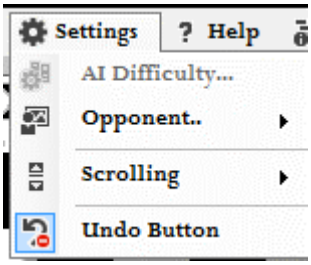
I have also added a line which updates the label which describes the state of the game, so that it the forfeit is immediately there.

To test it out, I simply make a few moves in the game. I then forfeit on white's third turn:



The history and label have been updated appropriately.

Some users may wish to disable the undo button, so I will add an option to disable it.

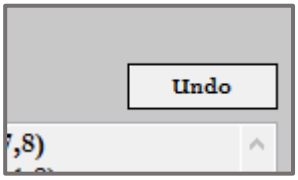


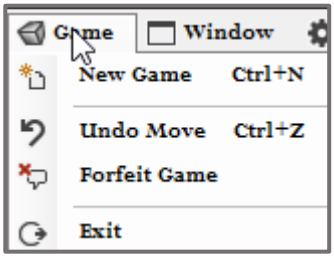
This will be a new option under the settings menu. To disable undoing, I will need to hide the button on the UI and disable the option under game (which will in turn disable the shortcut).

The code to do this is shown below.

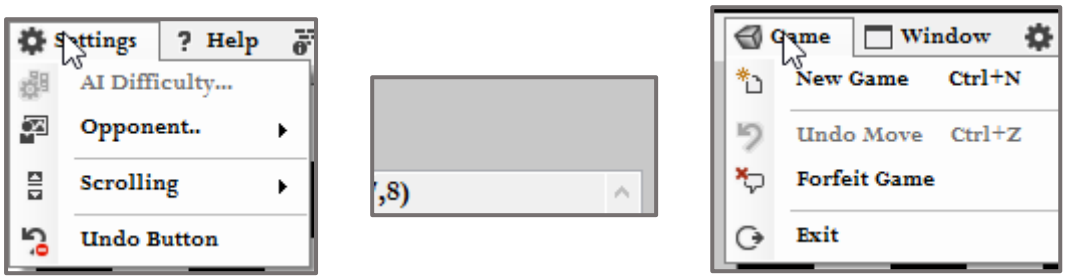
```
private void menu_setting_undo_Click(object sender, EventArgs e)
{
    bool enabled = !undo.Enabled;
    undo.Enabled = enabled;
    undo.Visible = enabled;
    menu_game_undo.Enabled = enabled;
    menu_setting_undo.Checked = enabled;
}
```

Before clicking:





After clicking:



Next, some users may not want the program to tell them where pieces can move to, so they can figure it out themselves. This is represented by the Movement Indicators option under UI Features. To implement this, I will create a new variable called `movementIndicators` which will store whether this setting is enabled or not:

```
public static bool movementIndicators = true;
```

Then I need to not draw any movement highlighted if this variable is false:

```
foreach (Square s in p.calculateMovement(false))
{
    pieceMovingMoves.Add(s);
    if (!movementIndicators) continue;
    Color c = Color.FromArgb(206, 17, 22);
    g.DrawRectangle(new Pen(Color.FromArgb(255, c)), s.X + 1, s.Y + 1, sf - 3, sf - 3);
```

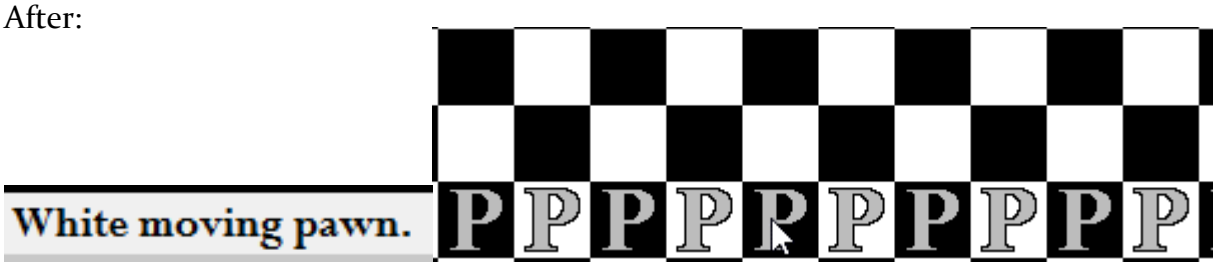
And then this can be used in the menu button code:

```
private void menu_window_ui_move_Click(object sender, EventArgs e)
{
    bool enabled = movementIndicators;
    movementIndicators = !enabled;
    menu_window_ui_move.Checked = !enabled;
}
```

To test it out, I will click a piece before and after turning off this feature and see what happens.

Before:

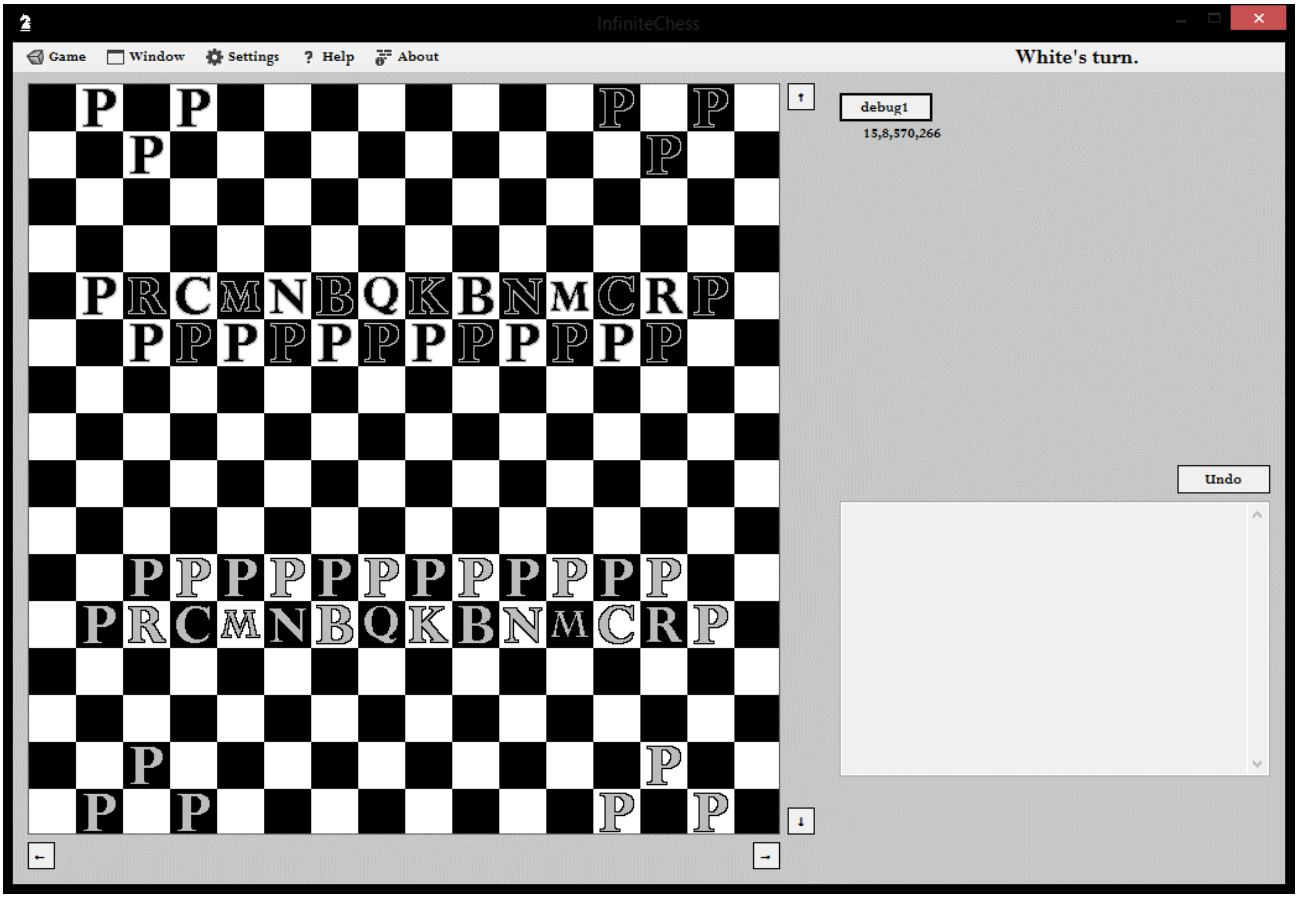
After:



General Gameplay Tests

I have added and changed a variety of things since the last testing section, so I think now is a good time to test everything together and ensure the game is working. These tests will be more complex than the previous piece movement tests, as they will use multiple different features of the game to make sure the components of the game interact and function correctly together.

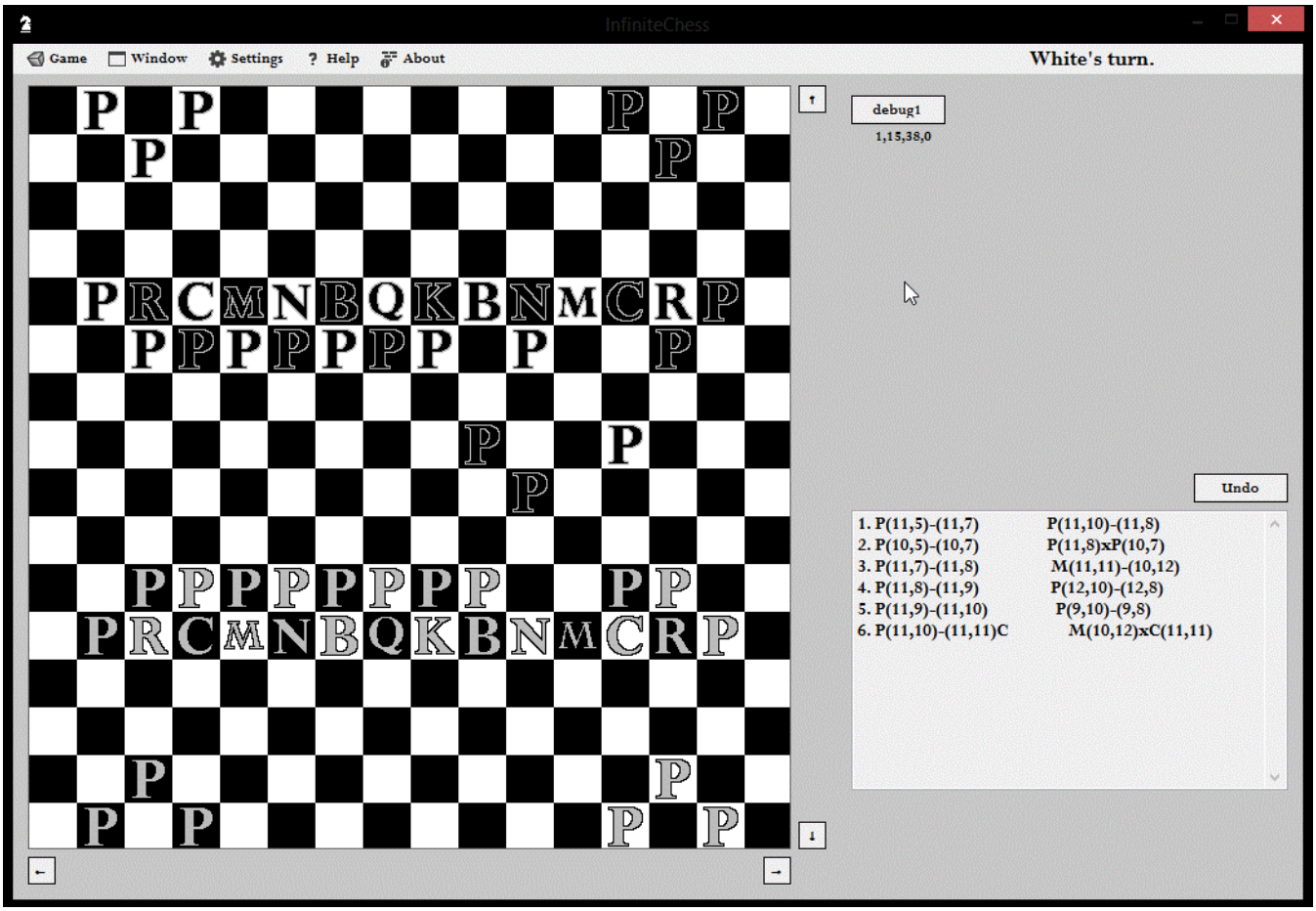
The initial condition of every test will be as the program looks right after starting it:

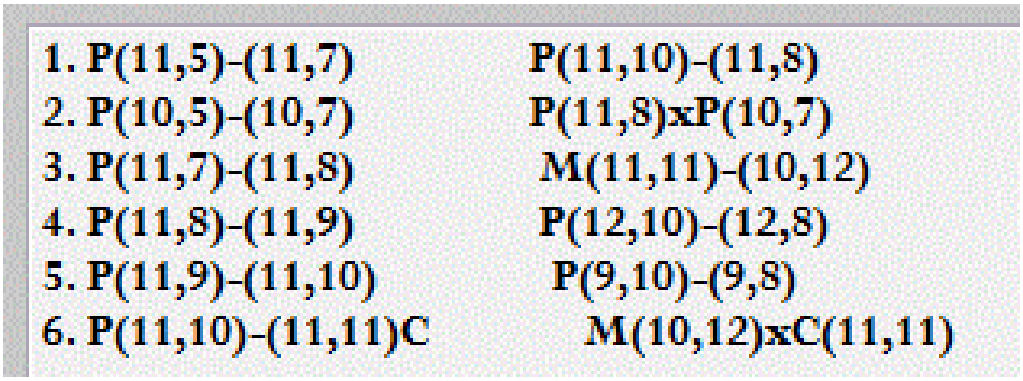


Additionally, these tests are difficult to document using screenshots alone. The final state of the test will be shown in a screenshot, but I will also provide videos of each test happening. (See Section 5 for information on where to find these videos).

Test 1

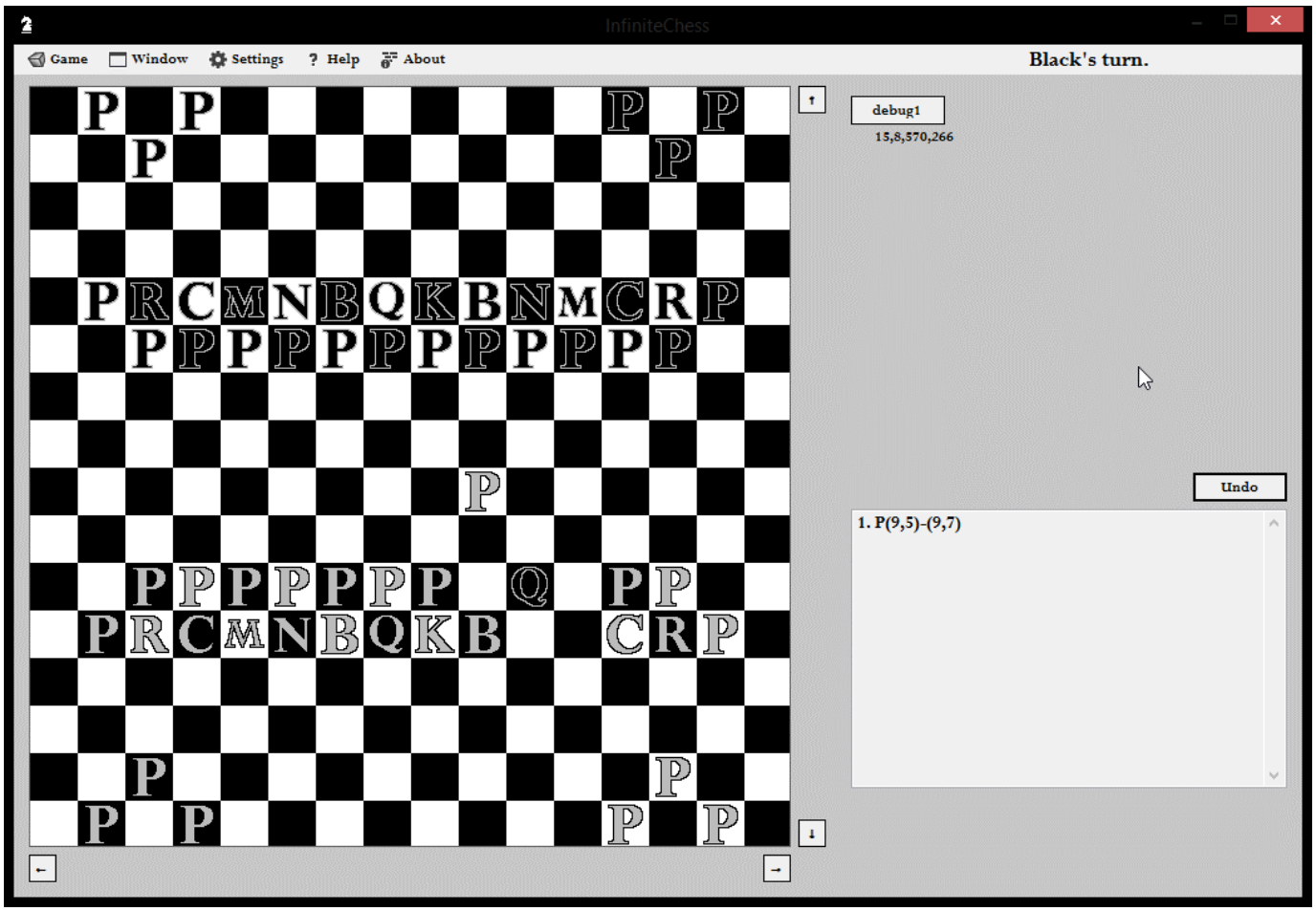
- White will move the same pawn every turn until it promotes and will promote to a chancellor. Black will move its own pieces out of the way of the pawn and then capture it after it has promoted.
- The final state is shown below. The promotion dialogue appeared once the pawn reached [11,11], and clicking the chancellor button changed it to a chancellor. This was correctly recorded in the move history. This chancellor was then captured by the mann, which was also correctly recorded in the history.

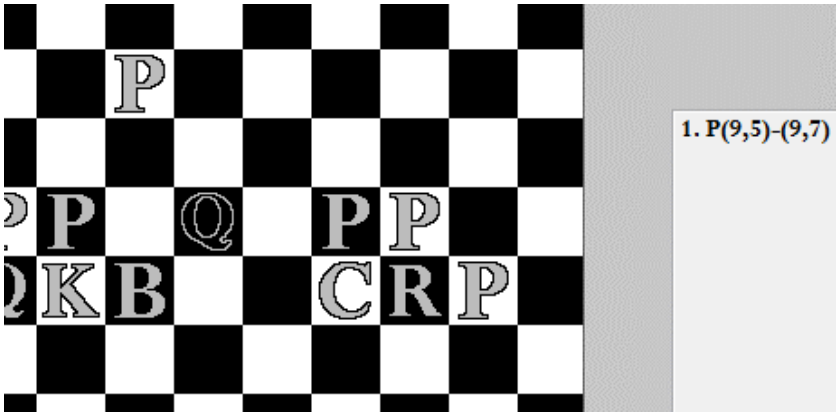




Test 2

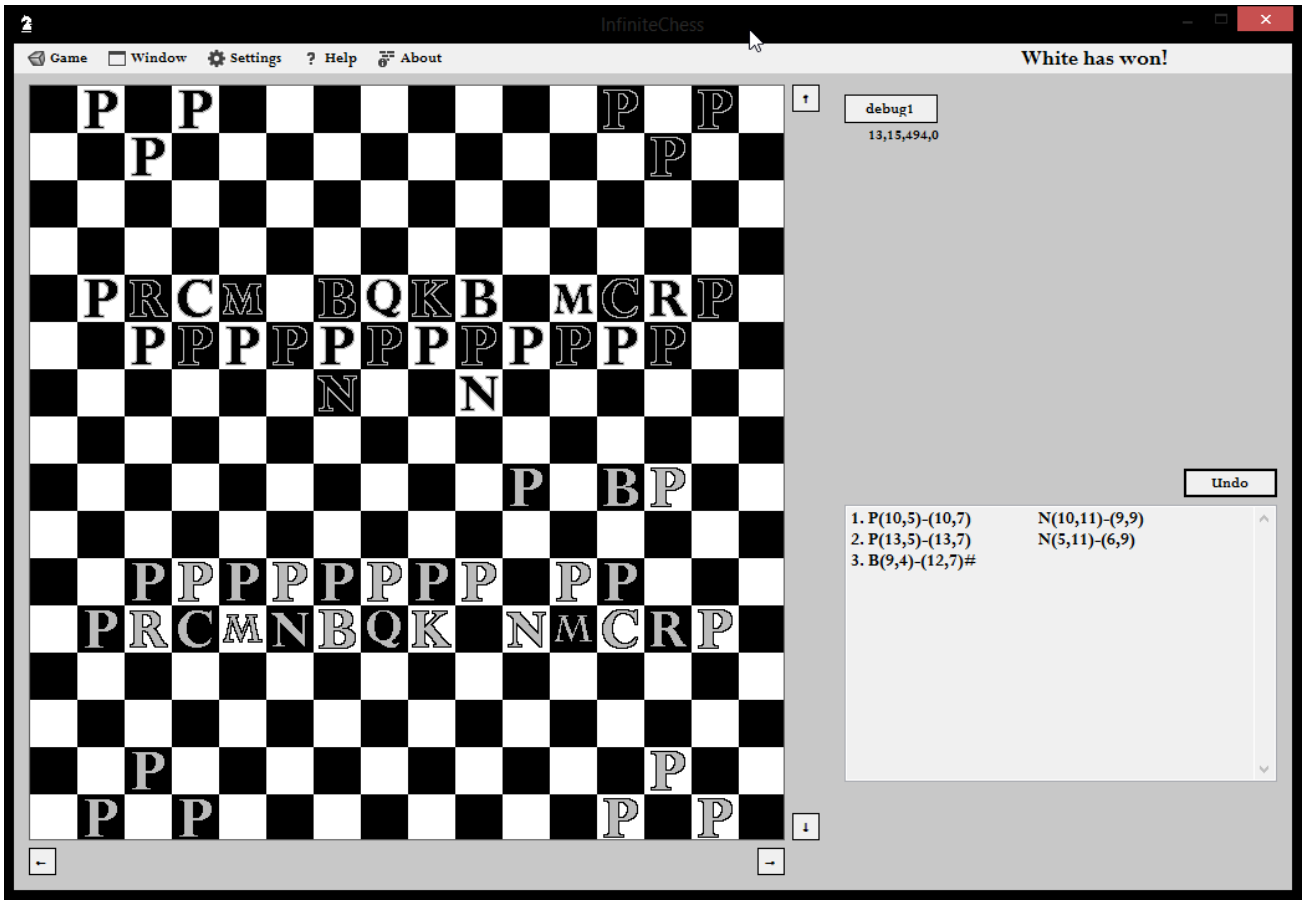
- I will create a black pawn one square away from being able to promote, where it also captured on promotion. I will promote the pawn to a queen, undo the move, and then promote to a rook. I will then use the menu button to start a new game.
- The state of the game after the initial capture is shown below. I was not able to perform the second promotion because the piece stayed as a queen, and the captured piece did not return either. I will look at why this happened and how it can be fixed at the end of this section. Starting a new game worked as expected.

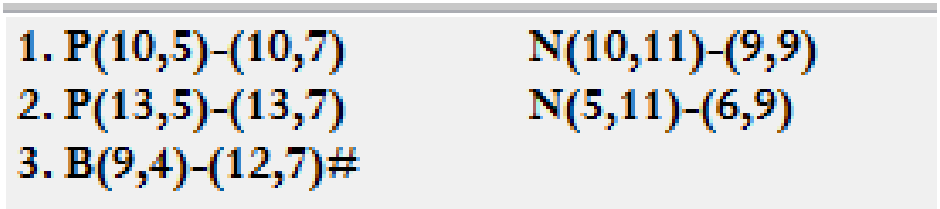




Test 3

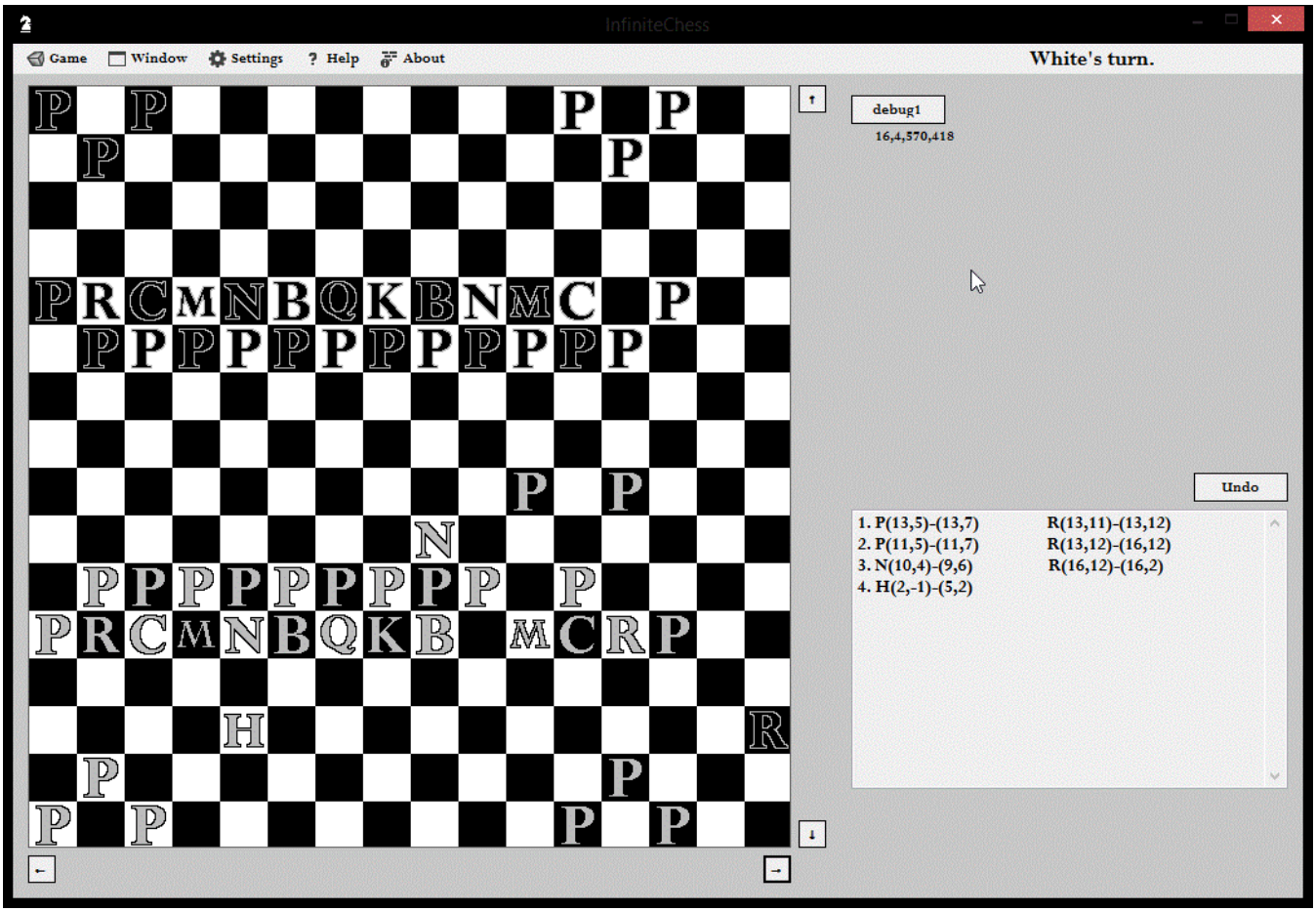
- I will play a few turns on both characters, then use the menu button to undo a black move, and then forfeit on white's next turn.
- After undoing black's move, the game correctly stated it was black's turn once again. Forfeiting then correctly displayed that white had won, and the win symbol (#) was appended to white's last move.

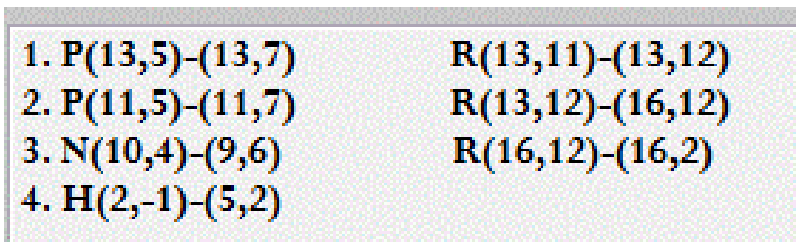




Test 4

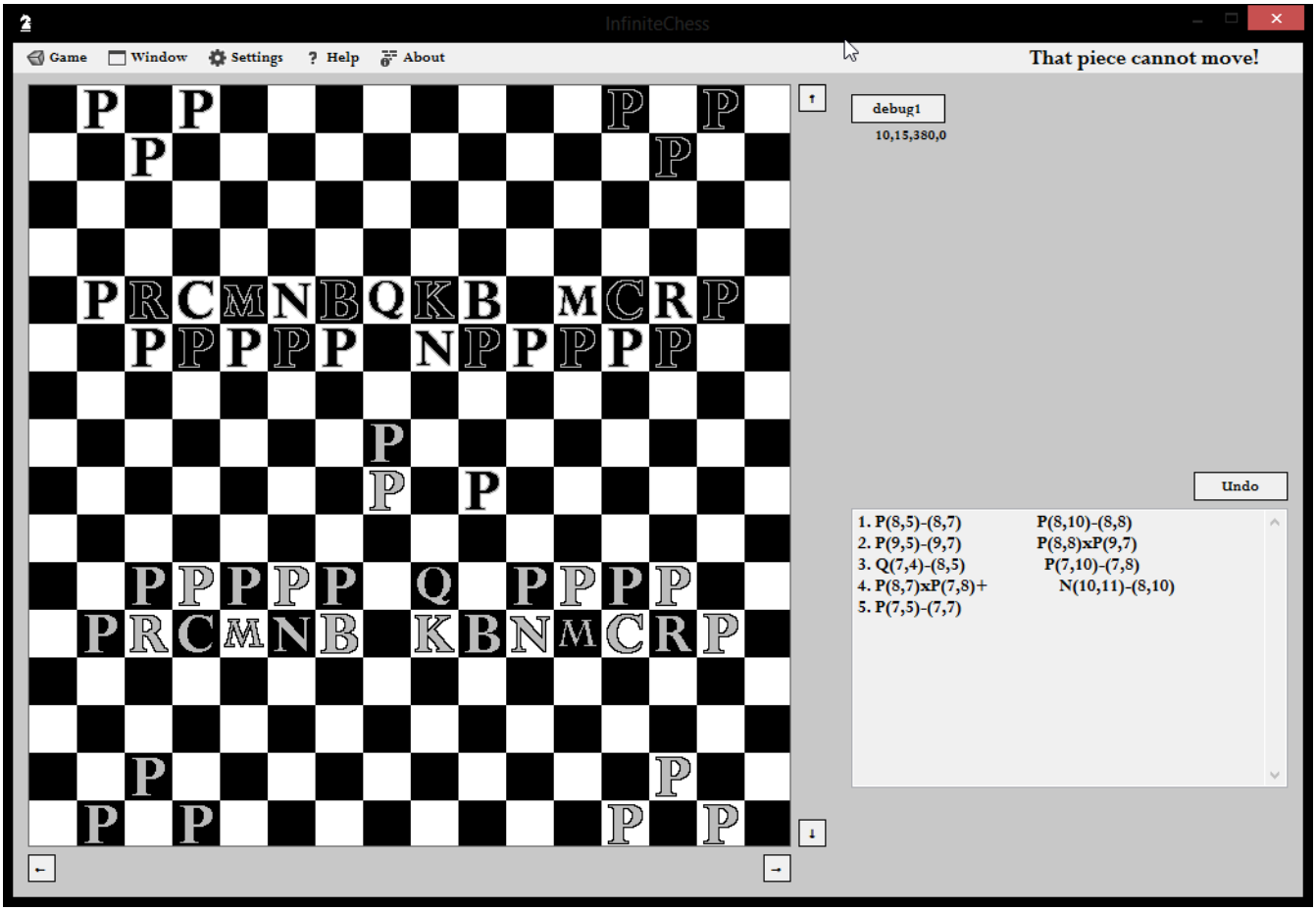
- The move history will be hidden using the menu button. Black will make some moves which will put white in check (which will involve scrolling the board), the move history will be unhidden, and then the last move will be undone.
- The final state is seen below. The history was hidden when the button was pressed, the game continued as normal while it was hidden. The history contained all the moves that occurred during the time it was hidden, including the check symbol (+). The move was then correctly removed from the history when it was undone.

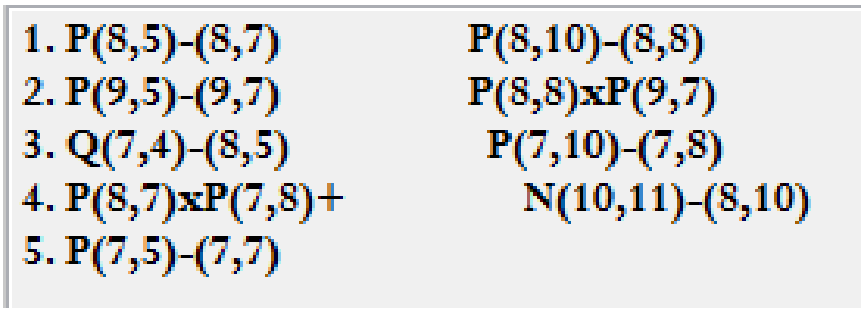


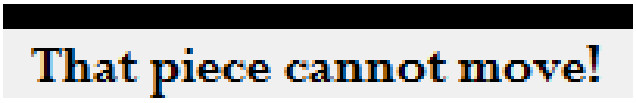


Test 5

- Movement indicators will be turned off. A series of moves will be taken that will put the black king in check via the white queen, and will then be blocked by a black knight. An attempt will be made to move the knight in such a way that would put the king back in check on the next move.
- Below is the state of the game after clicking the black knight. All pieces were able to move in the way I expect them to, the black king was correctly registered as being in check, and the black knight had no available moves.

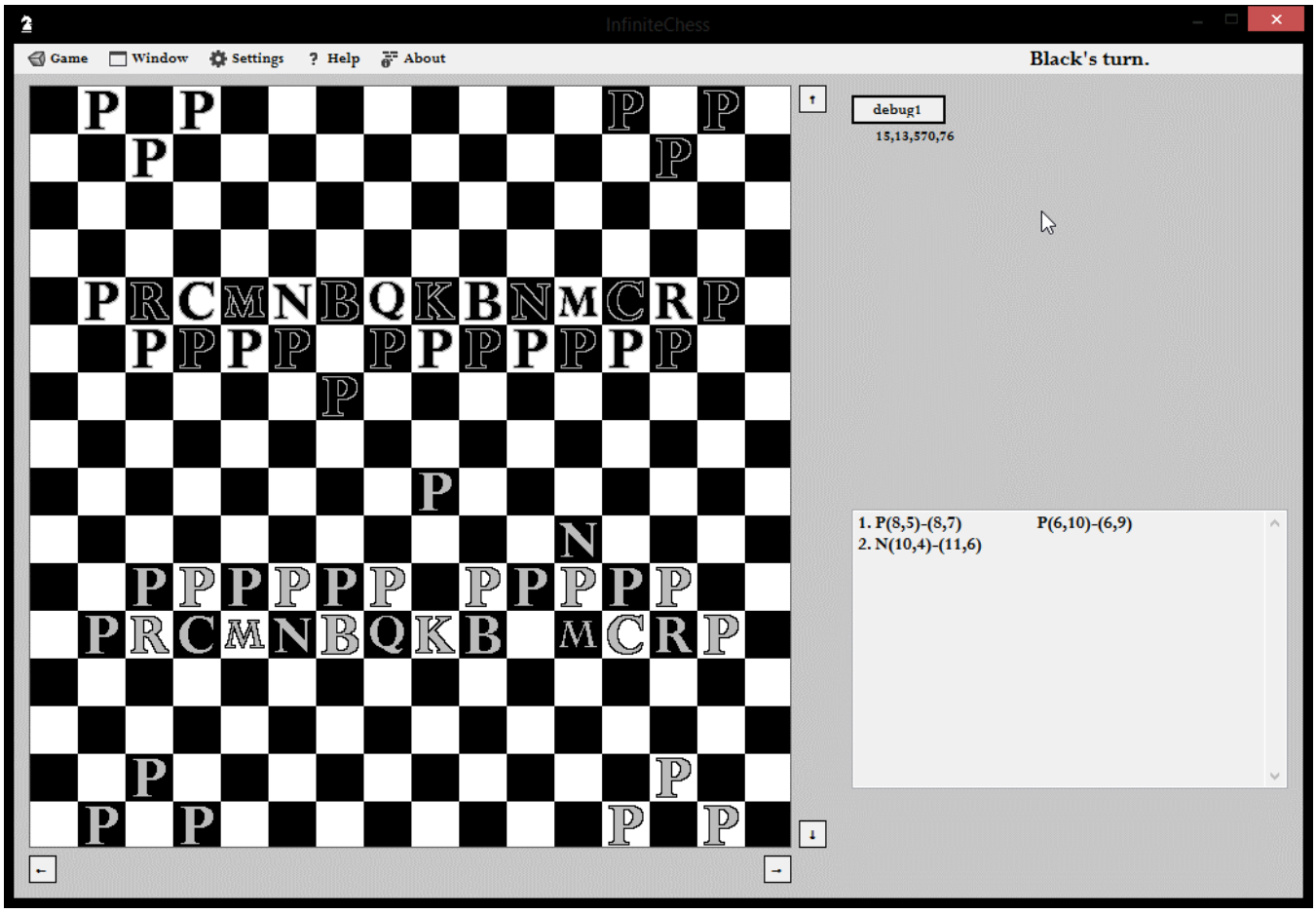






Test 6

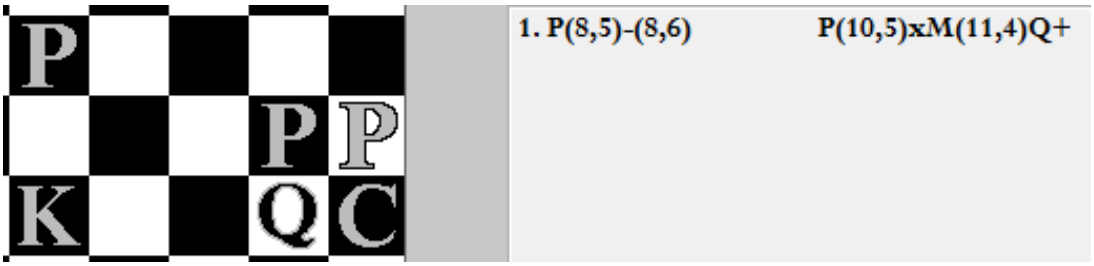
- I will then use the menu to disable the undo button. Some moves will be made by both players., and then attempt to use the undo button itself, the menu option for undoing, and the keybind (ctrl+z) for undoing. I will then re-enable the undo button and undo 3 moves.
- Below is the state of the game a few moves in after disabling the undo button. The undo button is gone and clicking on the space where it was does nothing. Clicking the menu icon does nothing, and using the keybind does nothing. After it was re-enabled, I could undo moves with both the button and the menu option correctly.



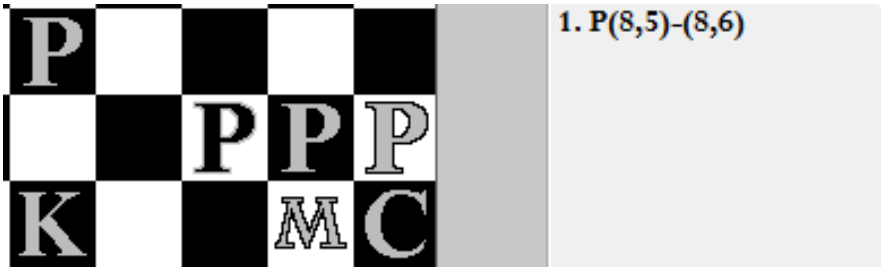
In test 2, I created a situation where a pawn captured a piece and promoted on the same turn. This causes the history entry for that move to have three letters in it, which I did not account for. Currently the code for undoing a move checks if the entry contains 2 letters or not. If it contains 2 letters and also contains an x, a piece must have been captured. If it does not contain an x, two letters means a pawn promoted. Since this is implemented using an `if else`, there is no way to deal with both simultaneously.

This is fairly easy to fix. First, I will change the enclosing if statement to check if there are 2 or more letters in the entry rather than exactly 2. Next, instead of having an `if else` to check whether the entry contains an x, I will replace the else to be another `if` which checks whether the last or second to last character of the entry is a letter. Having two `if` statements means that both of them can be true, which should mean that in the situation of a pawn capturing into a promotion, undoing will work as expected. I need to check both the last and second last characters because if a capture into promotion also causes check, checkmate or stalemate, the symbol for these three states will be after the letter to represent the promotion. To test this out I have set up a scenario where black will capture a piece which will promote a pawn and cause check on the first move:

After one turn:



Undoing:



The issue seems to be resolved, so I can now continue with development knowing that what I have done so far works.

AI

One of the core features of this game will of course be the AI to play against. First, I will create a variable to store the setting for whether AI is enabled:

```
public static bool opponentAI = false;
```

This will be true when the AI is playing, and false when not. With this variable, I can set up the menu buttons for opponent selection:

```
private void menu_setting_opp_human_Click(object sender, EventArgs e)
{
    setOpponent(false);
}
private void menu_setting_opp_ai_Click(object sender, EventArgs e)
{
    setOpponent(true);
}
private void setOpponent(bool ai) {
    menu_setting_opp_human.Checked = ai;
    menu_setting_opp_ai.Checked = ai;
    opponentAI = ai;
}
```

Now that I have a variable which holds whether the AI is enabled, I can create a function which is called instead of `handleTurn` for the AI. For now, I will decide that if the AI is enabled, black will always be the AI player, and white always the human player.

At the end of handleTurn, I have added the following line:

```
if (opponentAI && state.HasFlag((GameState)1)) { handleAITurn(); }
```

This means if the AI is enabled and it is black's turn, call `handleAITurn`. During this function, the player will not be able to interact with the game. After the turn is complete, control will return to the player.

The first thing the AI will need to be able to do is get a list of all the moves it can possibly make. A move will be defined by a piece that will move and the square it will move to. This will mean I want to store a list in which each entry is a `Piece` and a `Square`. However, these are two different data types, so storing them together in one list is not easy. I also don't want to make two separate lists. To solve this, I will make a new class, `AIMove`, which will have two attributes; a `Square` and a `Piece`. I can then construct a list of `AIMove` to store all the available moves.

```
public class AIMove
{
    public Square s;
    public Piece p;
    public AIMove(Piece piece, Square square) {
        p = piece; s = square;
    }
}
```

```
public void handleAITurn() {
    List<Piece> aipieces = pieces.FindAll(p => p.colour == PieceColour.BLACK);
    List<AIMove> moves = new List<AIMove>();
    foreach (Piece p in aipieces) {
        foreach (Square s in p.calculateMovement(false)) {
            moves.Add(new AIMove(p, s));
        }
    }
}
```

And then this is called in `handleTurn`:

```
if (opponentAI && state.HasFlag((GameState)1)) {
    handleAITurn();
}
```

This is of course a time-consuming operation. However, what I didn't expect was when the `handleAITurn` is being executed, not everything on the form is draw, and since everything is running on one thread, the form does not finish drawing until after the AI turn function completes. The way to resolve this is to use a BackgroundWorker to execute the function on another thread. This will allow the form to update itself on the main thread, and the time-consuming operation of handling the AI turn can be done on a background thread.

To do this, I create a new `BackgroundWorker` called `AIThread`, and create two methods for it that I will need:

```
public void AIThread_DoWork(object sender, DoWorkEventArgs e)
{
    BackgroundWorker bw = sender as BackgroundWorker;
    e.Result = handleAITurn(bw);
}
public void AIThread_WorkCompleted(object sender, RunWorkerCompletedEventArgs e)
{
    Debug.WriteLine("complete");
    Debug.WriteLine($"Returned Move: {e.Result}");
}
```

For this to work, I have had to change `handleAITurn` from type `void` to type `AIMove`. The function will now select a move and return it from the thread, and the move will be executed on the main thread.

Now I can execute the turn like this:

```
if (opponentAI && state.HasFlag((GameState)1)) {
    Debug.WriteLine("beginning");
    c.AIThread.RunWorkerAsync();
}
```

Currently, this function will return a random move from a random piece. It will not do anything or even set the turn back to the human player yet, it just picks a move and writes it to the debug console.

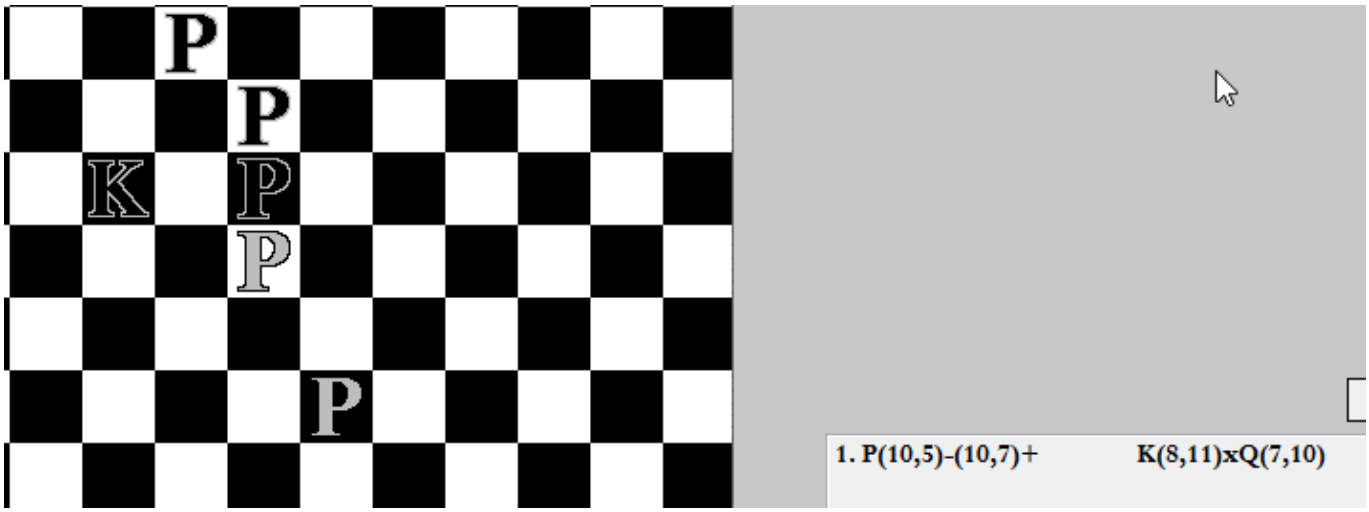
```
beginning
complete
Returned Move: KNIGHT,BLACK,10,11,380,152 -> (12, 12)
```

It is returning a move that seems to be a real move, and the form lag is gone. This is a good start. Before I work on the logic for picking a good move for the AI to play, I want to implement the ability for the AI to actually move and then set the turn back to the human. This is mostly done by just copying the code from `handleTurn`:

```
public void AIThread_WorkCompleted(object sender, RunWorkerCompletedEventArgs e)
{
    Debug.WriteLine($"Returned Move: {e.Result}");
    var colour = state.HasFlag(GameState.COLOUR) ? PieceColour.WHITE : PieceColour.BLACK;
    AIMove result = e.Result as AIMove;
    c.history.addMove(result.p, result.s);
    lastMove = null;
    bool cm = evaluateCheckMate(colour);
    if (evaluateCheck(colour)) {
        if (cm) {
            state ^= (GameState.WIN | GameState.COLOUR);
            c.history.addCheck(1);
        }
        else c.history.addCheck(0);
        state ^= GameState.CHECK;
    }
    else if (cm) {
        state ^= (GameState.STALE | GameState.COLOUR);
        c.history.addCheck(2);
    }
    state ^= (GameState.MOVE | GameState.COLOUR);
    c.drawBoard();
    c.stateLabel.Text = $"{parseState(state)}";
}
```

Of course, for the AI we won't be drawing any available moves and we won't need to check if the move the AI selected is part of the available moves. I will test this out using a scenario in which the AI has only one available move:

White is to move (and will move a piece that is not shown). Once it gets to black's turn, they will be in check, and the only move they can make is to capture the queen.



We can see that the AI successfully captured the queen, and the move history was correctly updated with this information. However, one problem I have noticed is that if I undo a move made by the AI, it will not make another move. However, if I called the AI turn every time an AI move is undone, I would never be able to undo a previous move (since undoing the move would cause another one to be take again instantly). What I need is a way to undo one black and one white move. As I've mentioned previously technically a "move" in chess is a turn by white and then a move by black. An individual turn by either player is referred to as a "ply". I want to have the option to undo either a move or a ply.

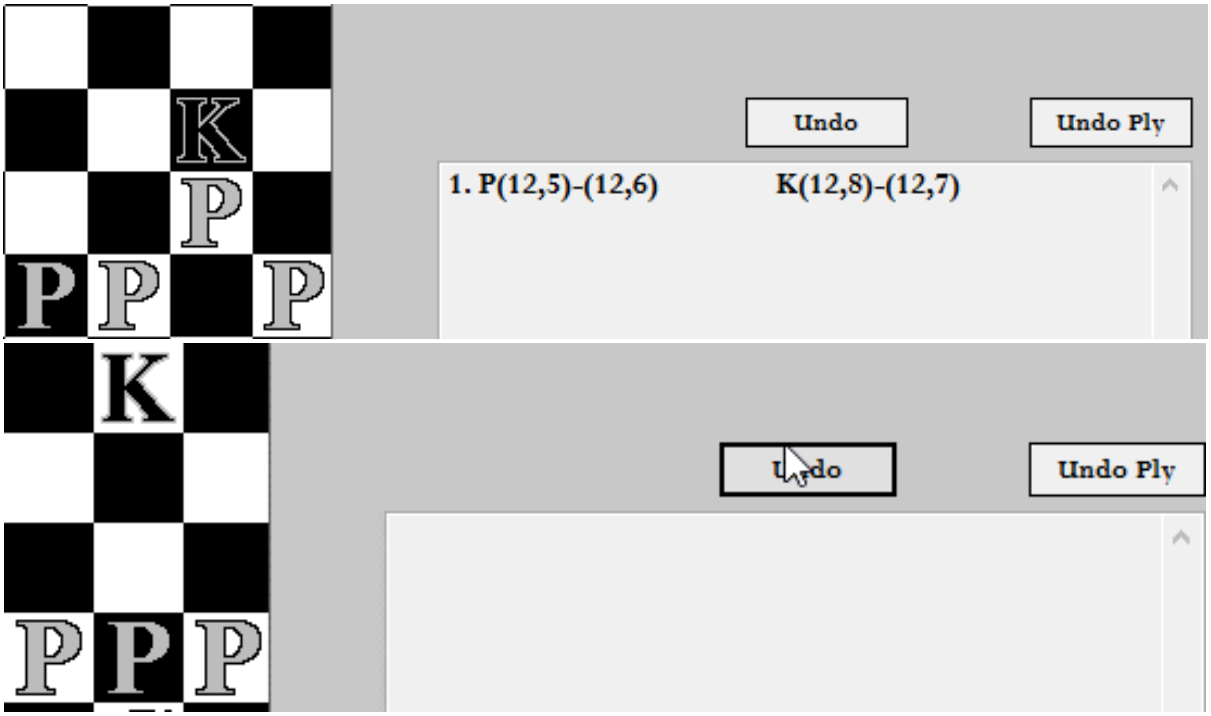
To do these, I will first need to loop the undoing function either once for a ply or twice for a move. This will be implemented by taking in a parameter and using it in a for loop:

```
public void undoMove(int num) {
    for (int i = 0; i < num; i++) {
```

The undo buttons then perform the following function:

```
private void undo_Click(object sender, EventArgs e)
{
    history.undoMove(1);
    drawBoard();
}
private void undo2_Click(object sender, EventArgs e)
{
    history.undoMove(2);
    drawBoard();
}
```

Testing it out:



Now every time a move is undone, I will check if the AI needs to make another move:

```
private void undo_Click(object sender, EventArgs e) => undo(1);
private void undo2_Click(object sender, EventArgs e) => undo(2);
private void undo(int i)
{
    history.undoMove(i);
    drawBoard();
    if (opponentAI && state.HasFlag((GameState)1))
        AIThread.RunWorkerAsync();
}
```

One last thing, currently if the AI (somehow) manages to get a pawn to the other end of the board, the promotion dialogue will still appear, and the player will end up choosing which promotion to use for the AI. This is obviously not a feature I want to keep in the game. For now, I will just make the AI always select a queen, and when I implement the AI logic, I will give it the ability to make a decision about which promotion to do.

```
if (opponentAI & state.HasFlag((GameState)1)) {
    p.changeType(PieceType.QUEEN);
    moveText += "Q";
}
```

The final thing I want to do before the logic; when the AI is deciding on a move, I do not want the player to be able to interact with the board. Since the AI is running on a background thread, if I did not explicitly stop the player from using the board, they could attempt to make moves while the AI is playing, which would cause some unexpected results. All I need to do is add an if statement to `OnMouseClick`:

```
protected override void OnMouseClick(MouseEventArgs e)
{
    Focus();
    if (opponentAI & state.HasFlag((GameState)3)) return;
    Square cursorSquare = findSquareByCoords(e.X, e.Y);
    Piece found = pieces.Find(p => p.square == cursorSquare);
    handleTurn(found, cursorSquare);
}
```

This now stops me from doing anything while the AI is deciding. No matter how fast I click now, I cannot do anything relating to the board during this time. Of course, the other functions of the form still work, which is the benefit of running the AI on a background thread.

To make the AI better at playing chess, I will need to evaluate all the moves that it can do. I will then need to assign each move a numerical value, and then select the move with the highest score to perform. As mentioned in the AI Design section, the simplest way to assign a value to a configuration of pieces is to count the number of each piece in the configuration and assign a value to each piece. The score of a configuration then becomes the sum of the scores of the pieces present in that configuration.

To iterate through each move, I will need to actually perform each move. Fortunately, this is also what is done in `calculateMovement`, so I can just copy the code from there and modify it for this purpose:

```
foreach (AIMove m in moves) {
    Square original = m.p.square;
    m.p.move(m.s, out Piece q);
    foreach (Piece y in pieces) {

    }
    m.p.move(original, out q);
    if (lastMove != null) { pieces.Add(lastMove); lastMove = null; }
}
```

Inside the foreach loop, there will be some code which adds a piece's value to the total. I haven't actually put any values into the game yet though, so I will create a new attribute in the `Piece` class which will hold the value of a piece. For now, I will make this dependent only on the piece type, but later on I could refine the value metric and take into account other factors.

```
switch (type) {
    case PieceType.PAWN: { value = 1 * sign; break; }
    case PieceType.BISHOP: { value = 5 * sign; break; }
    case PieceType.ROOK: { value = 7 * sign; break; }
    case PieceType.KNIGHT: { value = 3 * sign; break; }
    case PieceType.MANN: { value = 2 * sign; break; }
    case PieceType.HAWK: { value = 10 * sign; break; }
    case PieceType.CHANCELLOR: { value = 15 * sign; break; }
    case PieceType.QUEEN: { value = 25 * sign; break; }
    case PieceType.KING: { value = 200 * sign; break; }
    case PieceType.NONE: { value = 0; break; }
}
```

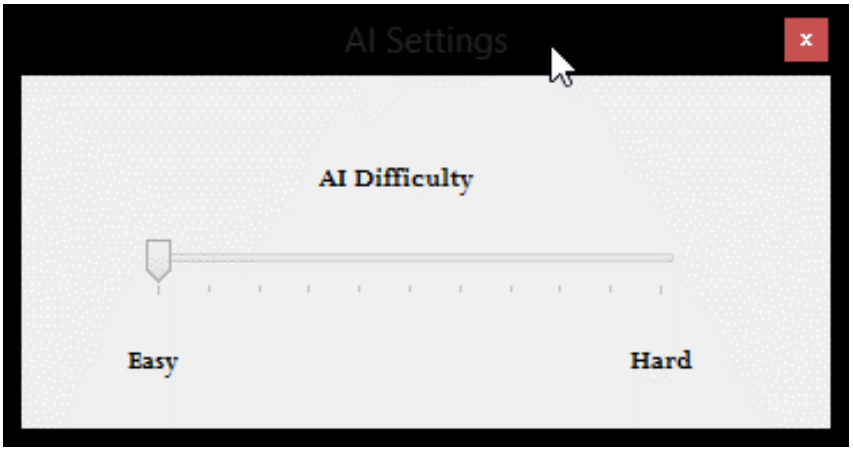
Sign in this case is either 1 or -1 depending on the colour of the piece. This means that the AI, which is playing with black pieces, wants to minimise the value of the board.

```
int best = 9999;
List<AIMove> bestMoves = new List<AIMove>();
foreach (AIMove m in moves) {
    int current = 0;
    Square original = m.p.square;
    m.p.move(m.s, out Piece q);
    foreach (Piece y in pieces) {
        current += y.value;
    }
    m.p.move(original, out q);
    if (lastMove != null) { pieces.Add(lastMove); lastMove = null; }
    if (current < best) {
        best = current;
        bestMoves.Clear();
        bestMoves.Add(m);
    }
    if (current == best) {
        bestMoves.Add(m);
    }
}
return bestMoves[(new Random()).Next(bestMoves.Count - 1)];
```

If there are multiple moves which all have the same score, then they are all stored, and then a random one is selected.

To add some variety and make it less predictable, I will introduce a chance for the AI to just select a completely random move. This also gives me an opportunity to implement a framework for difficulty settings; for now, I can just change the chance to perform a random move.

Difficulty will be defined as a number, with a maximum value of 100 and a minimum value of 0, with 100 being the most difficult setting. To select the difficulty, the menu button "AI Difficulty" will open a window which contains a slider. The user can then use the slider to select a difficulty in the range 0 to 100. 0.25



This value is then stored in a new variable, `AIDifficulty`:

```
public static int AIDIfficulty = 0;
```

And then as mentioned above, I will use this value to decide the chance that the AI picks a random move. This will be decided using the following formula:

```
if (new Random().NextDouble() > (0.25*(AIDIfficulty/100) + 0.82))
```

The constants I have chosen to use give the following probabilities for choosing a random move:

AI Difficulty	% Random	AI Difficulty	% Random
0	18	60	3
10	15.5	70	0.5
20	13	80	0
30	10.5	90	0
40	8	100	0
50	5.5		

So far, this AI works well enough. It's surprisingly good for the amount of logic it actually has, it is a decent challenge for someone with little experience. However, while it will aggressively go after the player's pieces, it doesn't really have any strategy other than that. If there's no moves in which it can capture a piece, it is essentially making random moves. For any experienced chess player, this wouldn't be a challenge at all. As mentioned in the AI Design section, I need to look more than one move ahead to make more informed decisions.

At the moment, searching one move deep takes about half a second. Searching another move down would take 0.5s * the number of possible moves. At the start of the game, there are about 150 possible moves for each player, so it would take 0.5s * 150 = 75s for the AI to make a move. Clearly, this is not feasible, a game would take an extraordinary amount of time if the AI needed over one minute to calculate each move.

I will try and decrease the amount of time it will take to calculate this by handling different possibilities in parallel. However, currently this is not possible with the way I have created the data structured in the program. All the functions relating to piece movement refer to and use the static variable `pieces`, rather than instance variables. This means that if I tried to call any of these functions in parallel, there would be stability errors because multiple threads will be accessing and modifying the same variable. Therefore, I will need to rewrite some functions to use instance variables instead, and then I can create a number of threads which all use their own instance of a board to perform calculations on.

`Piece.Move` now takes a parameter `localPieces`, and returns a `List<Piece>` instead of `void`:

```
public List<Piece> Move(Square s, out Piece pOut, List<Piece> localPieces) {
    Piece p = localPieces.Find(q => q.square == s);
    pOut = p;
    if (p != null) {
        localPieces.Remove(p);
        Chess.lastMove = p;
    }
    square = s;
    return localPieces;
}
```

`CalculateMovement` also takes in this new parameter:

```
public List<Square> calculateMovement(bool includeKings, List<Piece> localPieces) {
    List<Square> moves = calculateInitMovement(includeKings, localPieces);
    List<Square> newMoves = new List<Square>();
    Square original = square;

    foreach (Square s in moves) {
        newMoves.Add(s);
        localPieces = Move(s, out Piece q, localPieces);
        Square king = new Square();
        king = Chess.pieces.Find(p => p.type == PieceType.KING && p.colour == colour).square;
        foreach (Piece y in Chess.pieces) {
            if (y.colour == colour) continue;
            if (y.calculateInitMovement(true, localPieces).Contains(king)) { newMoves.Remove(s); break; }
        }
        localPieces = Move(original, out q, localPieces);
        if (Chess.lastMove != null) { localPieces.Add(Chess.lastMove); Chess.lastMove = null; }
    }
    return newMoves;
}
```

I can now parallelize the inner loop:

```
foreach (Piece p in aipieces)
{
    List<Square> pieceMoves2 = p.calculateMovement(false, localPieces);
    Parallel.ForEach(pieceMoves2, s =>
    {
        moves2.Add(new AIMove(p, s));
    });
}
```

To test out the speed of searching another move, I have implemented it in a way that is fast to do, rather than the best or nicest way:

```
foreach (AIMove m in moves) {
    Debug.WriteLine(m);
    int current = 0;
    Square original = m.p.square;
    localPieces = m.p.Move(m.s, out Piece q, localPieces);
    List<Piece> aipieces2 = localPieces.FindAll(p => p.colour == PieceColour.WHITE);
    List<AIMove> moves2 = new List<AIMove>();
    foreach (Piece p in aipieces)
    {
        List<Square> pieceMoves2 = p.calculateMovement(false, localPieces);
        Parallel.ForEach(pieceMoves2, s =>
        {
            moves2.Add(new AIMove(p, s));
        });
    }
    int best2 = -9999;
    List<AIMove> bestMoves2 = new List<AIMove>();
    foreach (AIMove m2 in moves2)
    {
        int current2 = 0;
        Square original2 = m.p.square;
        localPieces = m.p.Move(m.s, out Piece q2, localPieces);
        foreach (Piece y in localPieces) { current2 += y.value; }
        localPieces = m.p.Move(original2, out Piece _q2, localPieces);
        if (q2 != null) { localPieces.Add(q2); }
        if (current2 > best2)
        {
            best2 = current2;
            bestMoves2.Clear();
            bestMoves2.Add(m2);
        }
        if (current2 == best2)
        {
            bestMoves.Add(m2);
        }
```

Upon testing this out, it is still taking about 0.2-0.3s to do each move. This is an improvement from 0.5s, but the AI is still taking 30-40 seconds to make a move. This is still not an acceptable delay for making a move. I could maybe try and implement parallelism more explicitly, but this would take a lot of time to research, plan and implement. Instead, I will try and use some other techniques to make the AI more intelligent which will be less intensive.

Currently, each piece has an attribute, `value`, which keeps track of how much that piece is worth to the AI. This value is set when the piece is created, and never changes. However, I could change this based on other factors. For instance, if a piece is being protected by another piece, it should be worth more. This would give the AI the ability to make moves which account for future moves, without having to actually check any future moves.

This will be done in a new function called `updateValues`. This will iterate over each piece and update their values each turn. However, since this is constantly updated, I want to be able to find the base value for each piece. I will split `value` into two variables, `baseValue` and `addedValue`. `baseValue` will always be the same, and `addedValue` will be a modifier which will be added to the base value.

I will begin with pawns. First, if a piece is being protected by a pawn, it should be worth more, because there will be less incentive for the other player to take a piece if it protected by a pawn. As well as this, a pawn that is close to promoting should also be worth more.

```
if (p.type == PieceType.PAWN) {
    int colour = p.colour == PieceColour.WHITE ? 1 : -1;
    var query = from q in pieces
                where q.square.indexY == p.square.indexY + colour
                && Math.Abs(q.square.indexX - p.square.indexX) == 1
                select q;
    foreach (Piece t in query)
        t.addedValue += 200 * (t.colour == PieceColour.WHITE ? 1 : -1);
    if (colour == 1) {
        if (p.square.indexY == 7) p.addedValue += 400;
        if (p.square.indexY == 8) p.addedValue += 1000;
        if (p.square.indexY == 9) p.addedValue += 1500;
        if (p.square.indexY == 10) p.addedValue += 2500;
    }
    else {
        if (p.square.indexY == 8) p.addedValue -= 400;
        if (p.square.indexY == 7) p.addedValue -= 1000;
        if (p.square.indexY == 6) p.addedValue -= 1500;
        if (p.square.indexY == 5) p.addedValue -= 2500;
    }
}
```

I should also note I multiplied all the base values by 1000 so that I can have greater precision in the added values:

```
case PieceType.PAWN: { baseValue = 1000 * sign; break; }
case PieceType.BISHOP: { baseValue = 7000 * sign; break; }
case PieceType.ROOK: { baseValue = 15000 * sign; break; }
case PieceType.KNIGHT: { baseValue = 4000 * sign; break; }
case PieceType.MANN: { baseValue = 30000 * sign; break; }
case PieceType.HAWK: { baseValue = 12000 * sign; break; }
case PieceType.CHANCELLOR: { baseValue = 18000 * sign; break; }
case PieceType.QUEEN: { baseValue = 25000 * sign; break; }
case PieceType.KING: { baseValue = 200000 * sign; break; }
```

The result is that pieces that are protected by a pawn gain 200 value (this can apply more than once, i.e. maximum of 400). As well as this, pawns will get extra value based on how far they are from promoting. Pawns that are 4 squares from promoting get 400 value, 3 gets 1000, 2 gets 1500 and 1 gets 2500. The result of this is that the AI is very eager to move pieces forward and arrange them in a diagonal formation. The following is after 6 moves:

This is because the only other moves that will give any points to the AI are capturing pieces, so if there are no captures available, putting pawns in these locations will give the most points. Once I implement some additional values for other pieces, the AI should make a wider range of moves if it can't make a capture.

Next, manns are useful to guard other pieces from any direction, so they should have more value if they are next to other pieces.

```
if (p.type == PieceType.MANN) {
    var query = from q in pieces
                where Math.Abs(q.square.indexY - p.square.indexY) < 2
                && Math.Abs(q.square.indexX - p.square.indexX) < 2
                && q.colour == p.colour
                select q;
    if (query.Count() > 0) p.addedValue += 1000 * colour;
}
```

For rooks and chancellors, they are more useful if they are in the same row or column as enemy pieces (since they can then capture them if there is nothing in the way). Additionally, if they are on the same row or column as the enemy king, I will give extra value to the piece (this should encourage the AI to go for check/checkmate more often). The same logic can be applied to bishops and queens:

```
case PieceType.ROOK: {
    var query = from q in pieces
                where (p.square.indexX == q.square.indexX
                || p.square.indexY == q.square.indexY)
                && q.colour != p.colour
                select q;
    var king = from t in query
               where t.type == PieceType.KING
               select t;
    if (query.Count() > 0) p.addedValue += 2000 * colour;
    if (king.Count() > 0) p.addedValue += 2000 * colour;
    break;
}
case PieceType.CHANCELLOR: { goto case PieceType.ROOK; }
case PieceType.BISHOP: {
    var query = from q in pieces
                where (p.square.indexX - q.square.indexX
                == p.square.indexY - q.square.indexY)
                && q.colour != p.colour
                select q;
    var king = from t in query
                where t.type == PieceType.KING
                select t;
    if (query.Count() > 0) p.addedValue += 1500 * colour;
    if (king.Count() > 0) p.addedValue += 1500 * colour;
    break;
}
case PieceType.QUEEN: {
    var query = from q in pieces
                where (p.square.indexX - q.square.indexX
                == p.square.indexY - q.square.indexY)
                || (p.square.indexX == q.square.indexX
                || p.square.indexY == q.square.indexY)
                && q.colour != p.colour
                select q;
    var king = from t in query
                where t.type == PieceType.KING
                select t;
    if (query.Count() > 0) p.addedValue += 2500 * colour;
    if (king.Count() > 0) p.addedValue += 2500 * colour;
    break;
}
```

One problem I have noticed with the AI is that it will often use long range pieces to capture my own pieces from across the board, without protecting the piece it sent to capture at all. To try and counteract this, I will remove points for pieces that are very far from any other pieces of the same colour:

```
var far = from q in pieces
          where Math.Abs(p.square.indexX - q.square.indexX) < 4
          && Math.Abs(p.square.indexY - q.square.indexY) < 4
          && q.colour == p.colour
          select q;
if (far.Count() == 1) { p.addedValue -= 4000 * colour; }
if (far.Count() == 2) { p.addedValue -= 100 * colour; }
```

Now to make the AI Difficulty have an extra layer, I will cause it to ignore a certain amount of added value on lower difficulties:

```
if (colour == 1) p.addedValue = Math.Max(p.addedValue - (1000 - 10 * AIDIfficulty), 0);
else p.addedValue = Math.Min(p.addedValue + (1000 - 10 * AIDIfficulty), 0);
```

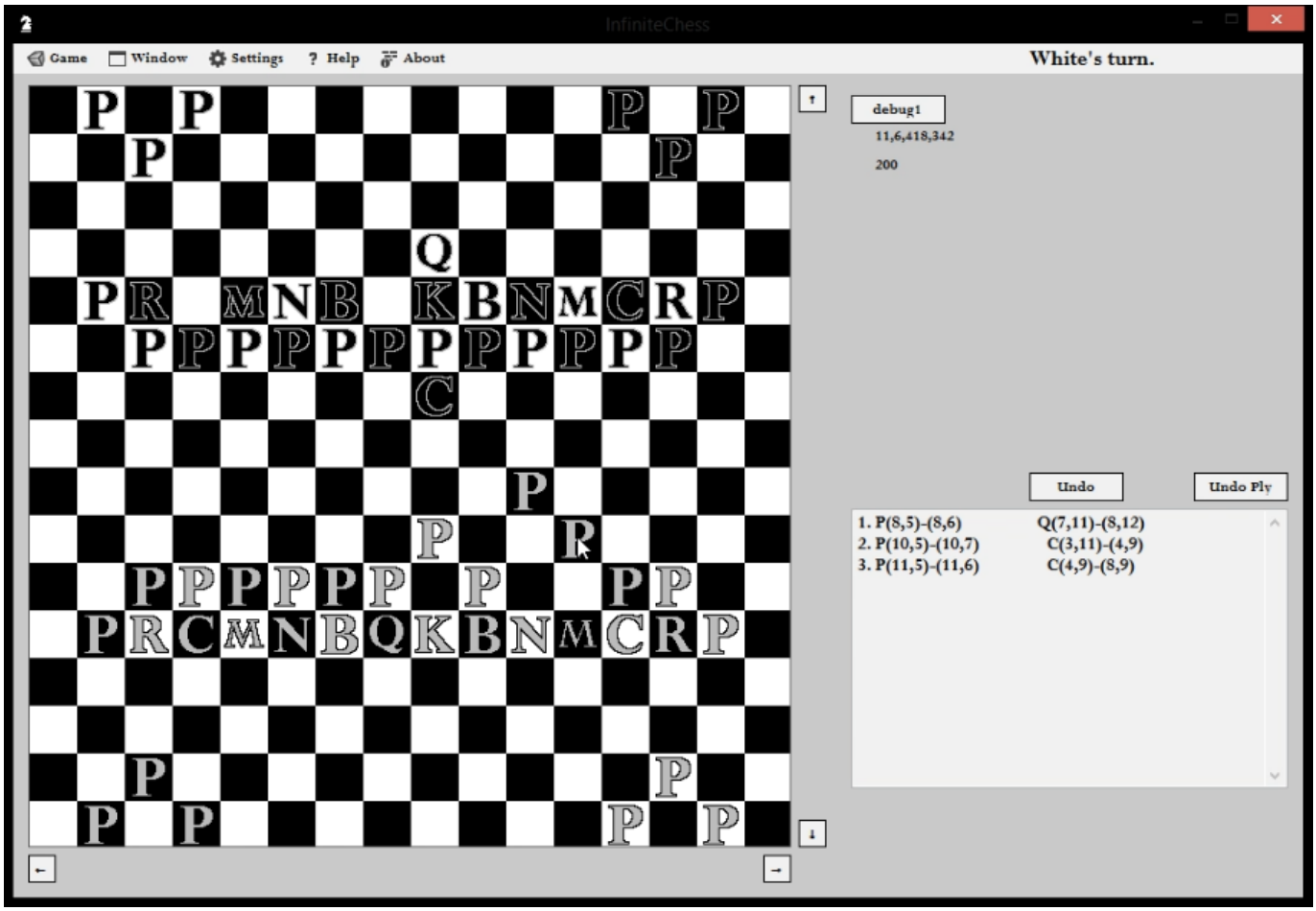
This means that the lowest AI difficulty will "ignore" 1000 points of added value (but it cannot pass 0), and the highest difficulty will ignore 0 value. This means the difficulty now has two meanings, which is the sort of complexity I am looking for.

AI Testing

As in the last testing section, it is difficult to accurately demonstrate the process and outcomes of these tests through (a reasonable number of) screenshots, so I will once again create videos of these tests. These tests will be to ensure that the other features of the game work as expected in combination with the AI.

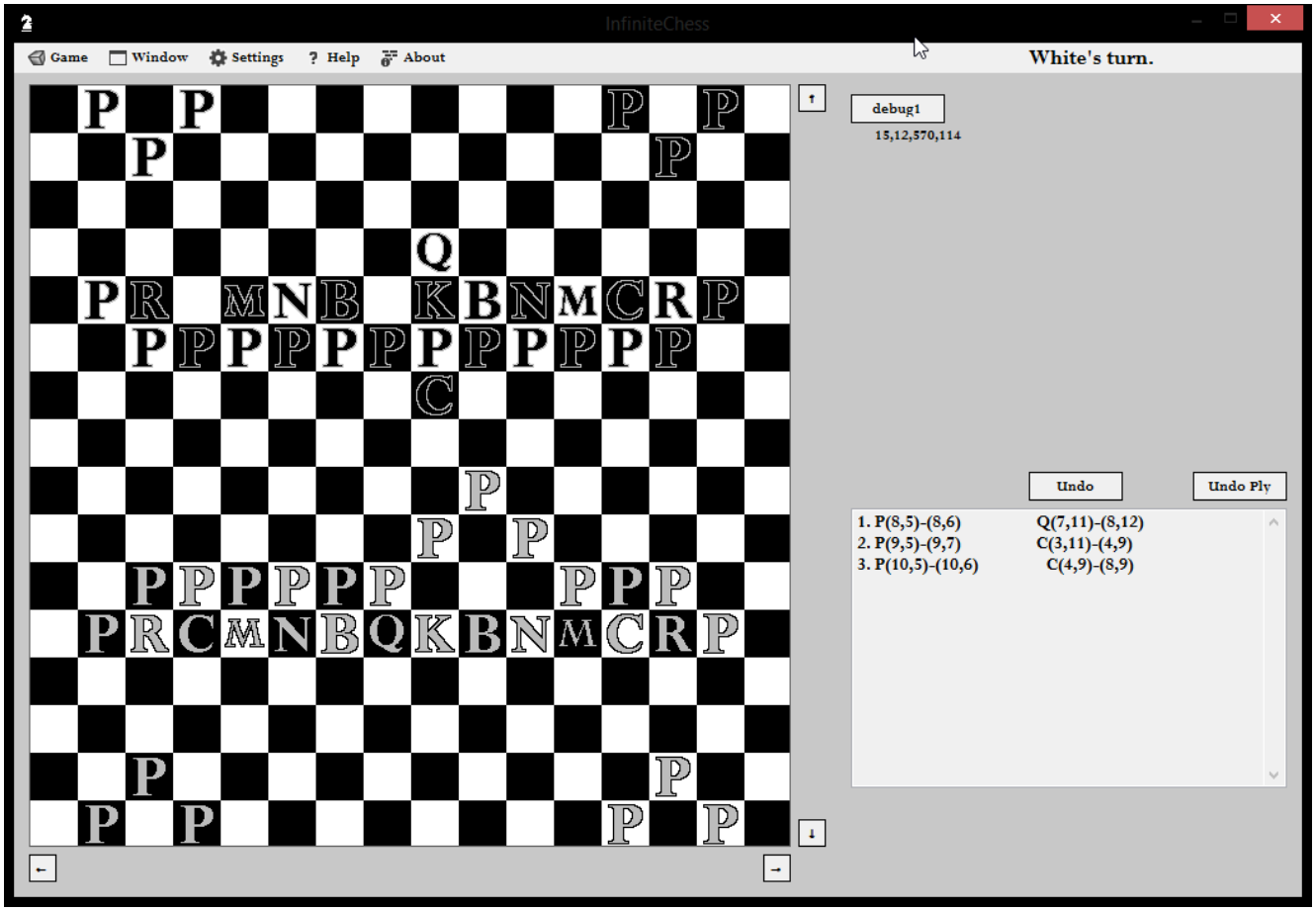
Test 1

- I will set the opponent to AI, play a few moves, start a new game, and then play some more moves.
- The AI should continue to make moves even after I start a new game.
- Below is the result after the game had been reset and more moves had been played. The AI made moves for black even after a new game had been started.



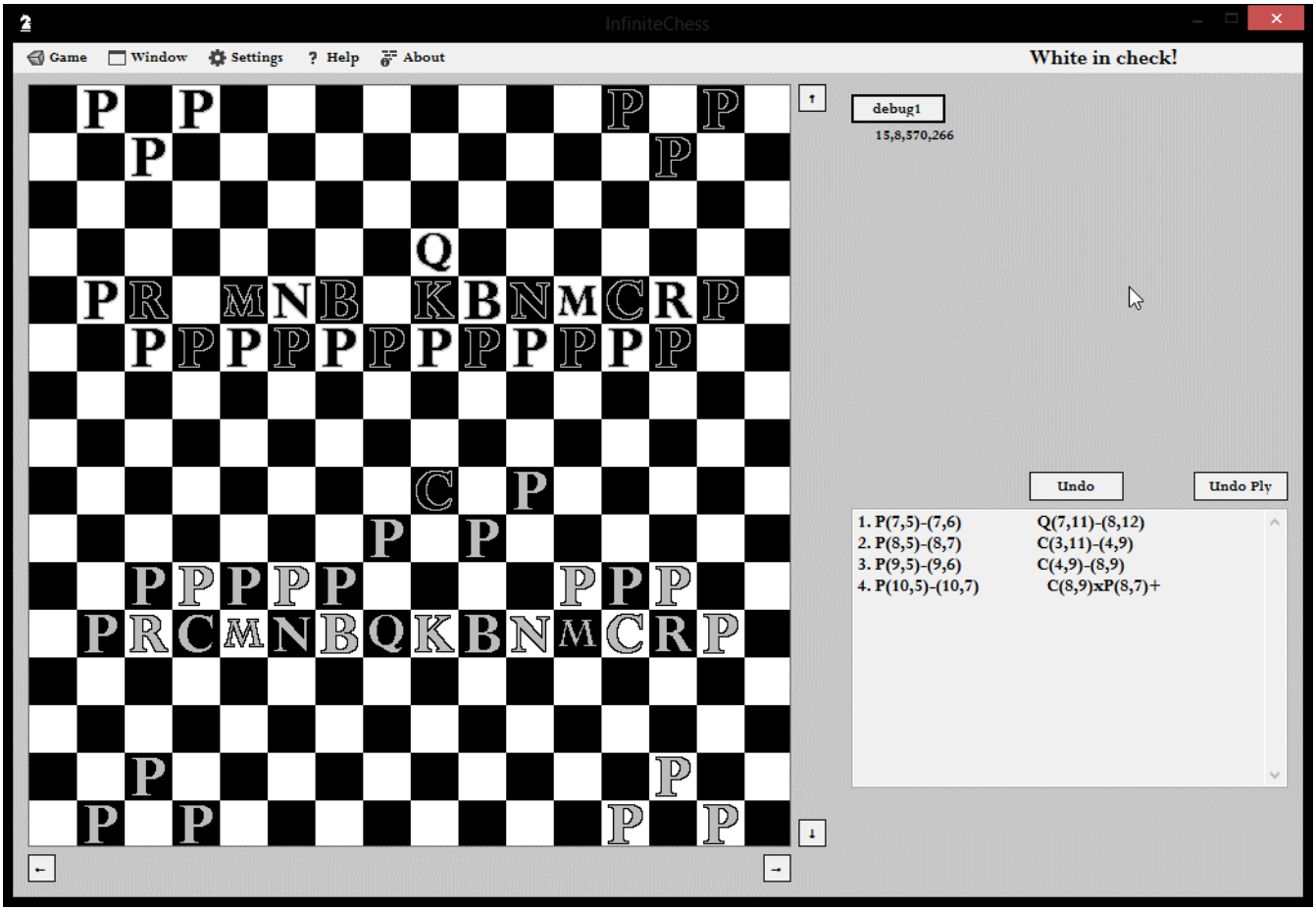
Test 2

- I will enable the AI and play a few moves. I will then use the forfeit option from the menu. The AI should not play any more moves. I will then undo the last move and make another move. The AI should continue making moves.
- Below is a screenshot after I forfeit and made additional moves. The AI did not make a move after I had forfeit. When I performed an undo on my forfeit and played another move, the AI responded correctly.



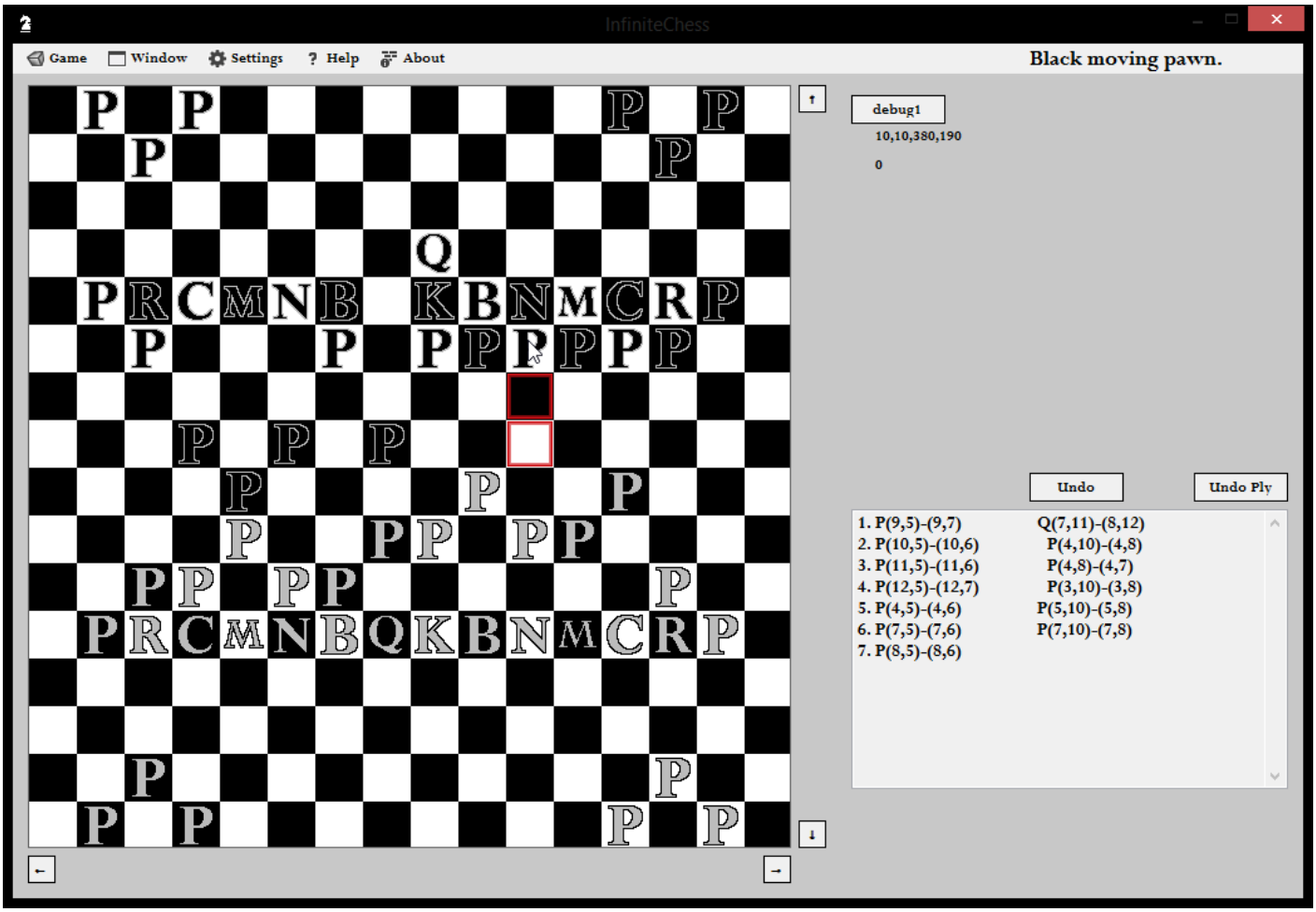
Test 3

- I will set the opponent to AI, then hide both movement indicators and move history. I will then make some moves, and the turn both the features back on.
- The AI should continue to make moves while these features are disabled, and all the moves that occurred should be in the history when it is reenabled.
- Below is the game after the history and indicators had been reenabled. The AI made moves while these features were disabled, and the history correctly recorded the moves that happened while it was hidden.



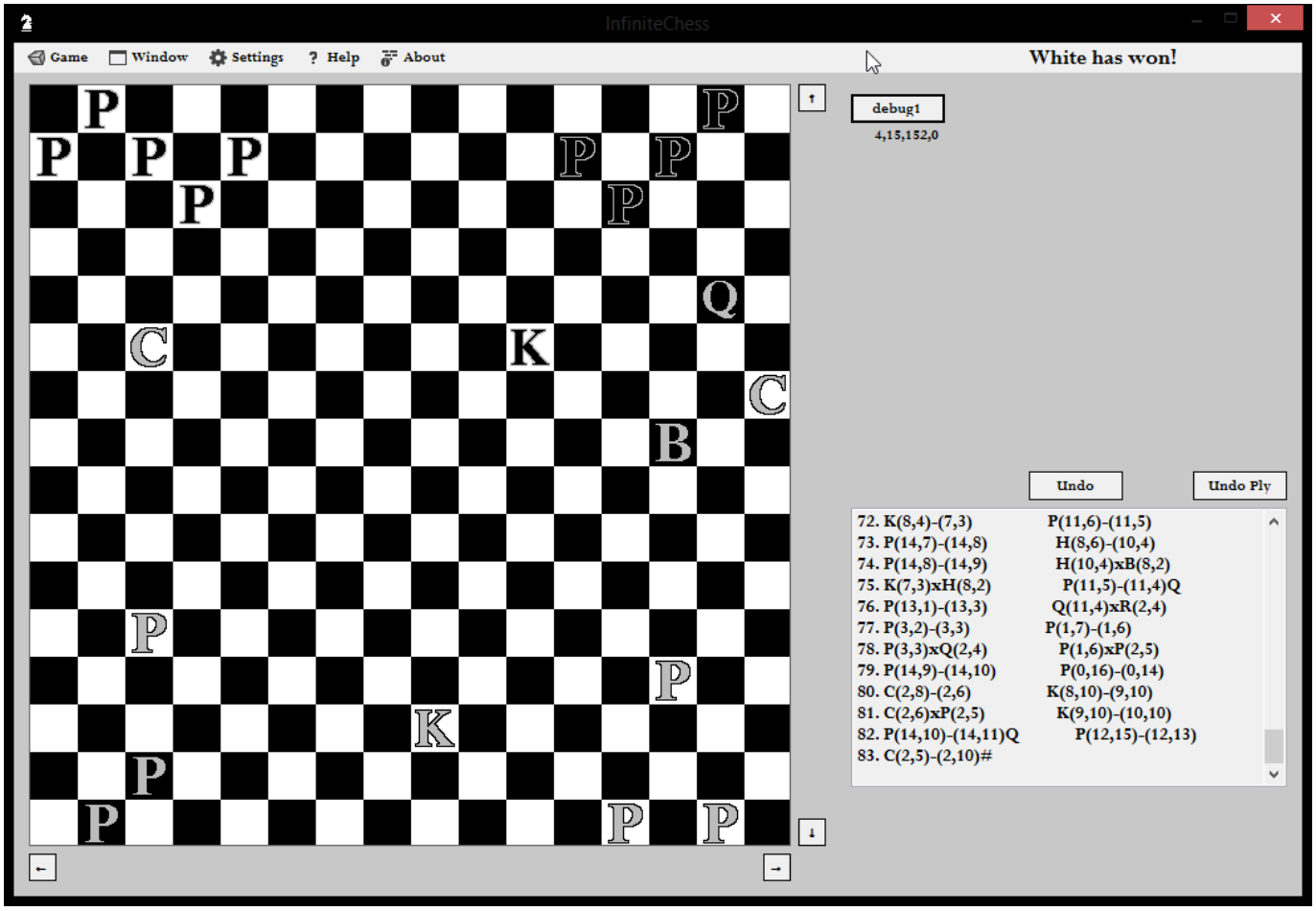
Test 4

- I will set the opponent to AI, and then set the difficulty to the highest setting. I will then play a few moves, and then set the opponent to human.
- The AI should make some moves (none of which will be completely randomly selected). After the opponent is set to human, the AI should not make any moves, and I should have control over the black pieces.
- The screenshot below shows the game after I have set the opponent back to human. The movement indicator for black can be seen, which shows that the user has control of the black pieces (as opposed to the AI).



Test 5

- I will disable the undo button, set the difficulty to maximum, and then play a full game with the AI.
- The AI did not make any moves after I won the game.
- The AI played at the level I expected; making some basic decisions but nothing too strategic.
- The AI successfully put me in check a few times, and even promoted a pawn to a queen.



From these tests, I can conclude that the AI works as I expect it to. It may not be particularly challenging to an experienced player, but for most people I think it will be sufficient, especially as this game is in many ways different to regular chess.

Saving and Loading

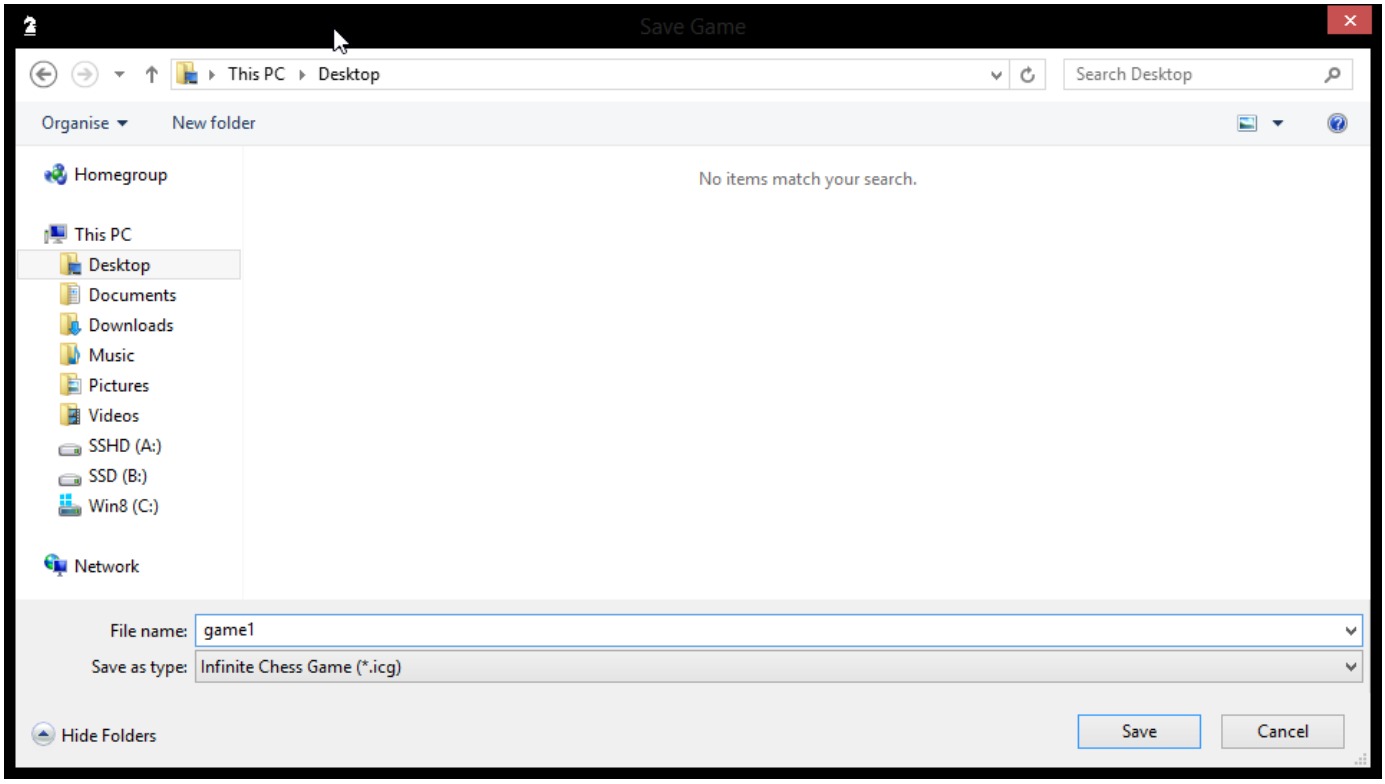
I think saving and loading will be an important feature, since games could end up taking a long time, especially if it is two humans playing. To be able to recreate a game, I would need to have two things: the board layout, and the move history. Technically I could save just the history and play out all the moves from the history to reach the board state when it was saved, but this seems needlessly inefficient. As well as this, I will need to store the bounds of the board, because players may have moved pieces out of the default boundaries, and I will need the game state.

Visual Studio provides a `SaveFileDialog` as part of Windows Forms, so all I need to do is specify what data I want to save. To read the data, I will need to split up the save file into pieces that I can then interpret to recreate the game. I will first store a list of pieces, with each attribute separated by a comma, and each piece separated by a semicolon. I will then store each entry in the move history, separated by semicolons. Finally, I will have the bounds values and the game state, separated by semicolons. Each of these three sections will be separated by a pipe (|). To implement this, I use a `StringBuilder` to set up the string to be stored, and write it using a `StreamWriter`:

```
SaveFileDialog save = new SaveFileDialog();
save.Filter = "Infinite Chess Game|*.icg";
save.Title = "Save Game";
save.ShowDialog();
if (save.FileName != "")
{
    StringBuilder sb = new StringBuilder();
    foreach (Piece p in pieces) {
        sb.Append($"{p.type},{p.square.indexX},{p.square.indexY},{p.colour},{p.PawnData},{p.addedValue};");
    }
    sb.Append("|");
    foreach (string s in history.moves) {
        sb.Append($"{s};");
    }
    sb.Append($"|{bounds[0]};{bounds[1]};{bounds[2]};{bounds[3]};{(int)state}");
    using (StreamWriter sw = new StreamWriter(save.FileName))
    {
        sw.WriteLine(sb);
        sw.Close();
    }
}
```

This function is attached to the save button in the menu (which also has shortcut ctrl+s).

To test it out, I will make a single move in a game and press save.



The save dialog opens correctly. The files are being saved with an extension I have made up, .icg. In reality, they are just plaintext, so after saving this game as "game1", I can open it in a text editor and look at the contents to ensure it worked correctly.

Below is a screenshot of the file I just saved in the game. I have added new lines at some points to make it easier to screenshot, but these are actually stored all on one line. The second last line is the contents of the move history, and the last is the bounds and game state.

```
1  PAWN,0,-1,WHITE,True,0;PAWN,1,0,WHITE,True,0;PAWN,2,1,WHITE,True,200;PAWN,3,0,WHITE,True,200;
2  PAWN,4,-1,WHITE,True,0;PAWN,11,-1,WHITE,True,0;PAWN,12,0,WHITE,True,0;PAWN,13,1,WHITE,True,200;
3  PAWN,14,0,WHITE,True,200;PAWN,15,-1,WHITE,True,0;PAWN,1,4,WHITE,True,0;PAWN,2,5,WHITE,True,0;
4  PAWN,3,5,WHITE,True,0;PAWN,4,5,WHITE,True,0;PAWN,5,5,WHITE,True,0;PAWN,6,5,WHITE,True,0;
5  PAWN,7,5,WHITE,True,0;PAWN,8,6,WHITE,False,200;PAWN,9,5,WHITE,True,0;PAWN,10,5,WHITE,True,0;
6  PAWN,11,5,WHITE,True,0;PAWN,12,5,WHITE,True,0;PAWN,13,5,WHITE,True,200;PAWN,14,4,WHITE,True,0;
7  HAWK,2,-1,WHITE,False,0;HAWK,13,-1,WHITE,False,0;ROOK,2,4,WHITE,False,1000;
8  CHANCELLOR,3,4,WHITE,False,1000;MANN,4,4,WHITE,False,0;KNIGHT,5,4,WHITE,False,0;
9  BISHOP,6,4,WHITE,False,500;QUEEN,7,4,WHITE,False,1500;KING,8,4,WHITE,False,0;BISHOP,9,4,WHITE,False,0;
10 KNIGHT,10,4,WHITE,False,0;MANN,11,4,WHITE,False,0;CHANCELLOR,12,4,WHITE,False,1000;
11 ROOK,13,4,WHITE,False,1000;PAWN,0,16,BLACK,True,0;PAWN,1,15,BLACK,True,0;PAWN,2,14,BLACK,True,-200;
12 PAWN,3,15,BLACK,True,-200;PAWN,4,16,BLACK,True,0;PAWN,11,16,BLACK,True,0;PAWN,12,15,BLACK,True,0;
13 PAWN,13,14,BLACK,True,-200;PAWN,14,15,BLACK,True,-200;PAWN,15,16,BLACK,True,0;PAWN,1,11,BLACK,True,0;
14 PAWN,2,10,BLACK,True,0;PAWN,3,10,BLACK,True,0;PAWN,4,10,BLACK,True,0;PAWN,5,10,BLACK,True,0;
15 PAWN,6,10,BLACK,True,0;PAWN,7,10,BLACK,True,0;PAWN,8,10,BLACK,True,0;PAWN,9,10,BLACK,True,0;
16 PAWN,10,10,BLACK,True,0;PAWN,11,10,BLACK,True,0;PAWN,12,10,BLACK,True,0;PAWN,13,10,BLACK,True,-200;
17 PAWN,14,11,BLACK,True,0;HAWK,2,16,BLACK,False,0;HAWK,13,16,BLACK,False,0;ROOK,2,11,BLACK,False,-1000;
18 CHANCELLOR,3,11,BLACK,False,-1000;MANN,4,11,BLACK,False,0;KNIGHT,5,11,BLACK,False,0;
19 BISHOP,6,11,BLACK,False,0;QUEEN,8,12,BLACK,False,-4000;KING,8,11,BLACK,False,0;
20 BISHOP,9,11,BLACK,False,-500;KNIGHT,10,11,BLACK,False,0;MANN,11,11,BLACK,False,0;
21 CHANCELLOR,12,11,BLACK,False,-1000;ROOK,13,11,BLACK,False,-1000;
22 |P(8,5)-(8,6)PU1;Q(7,11)-(8,12);
23 |-1;17;-1;17;0
```

This seems to be correct, all the pieces and their attributed have been stored, along with the move history. Now I will need to write a function to read this data from a file.

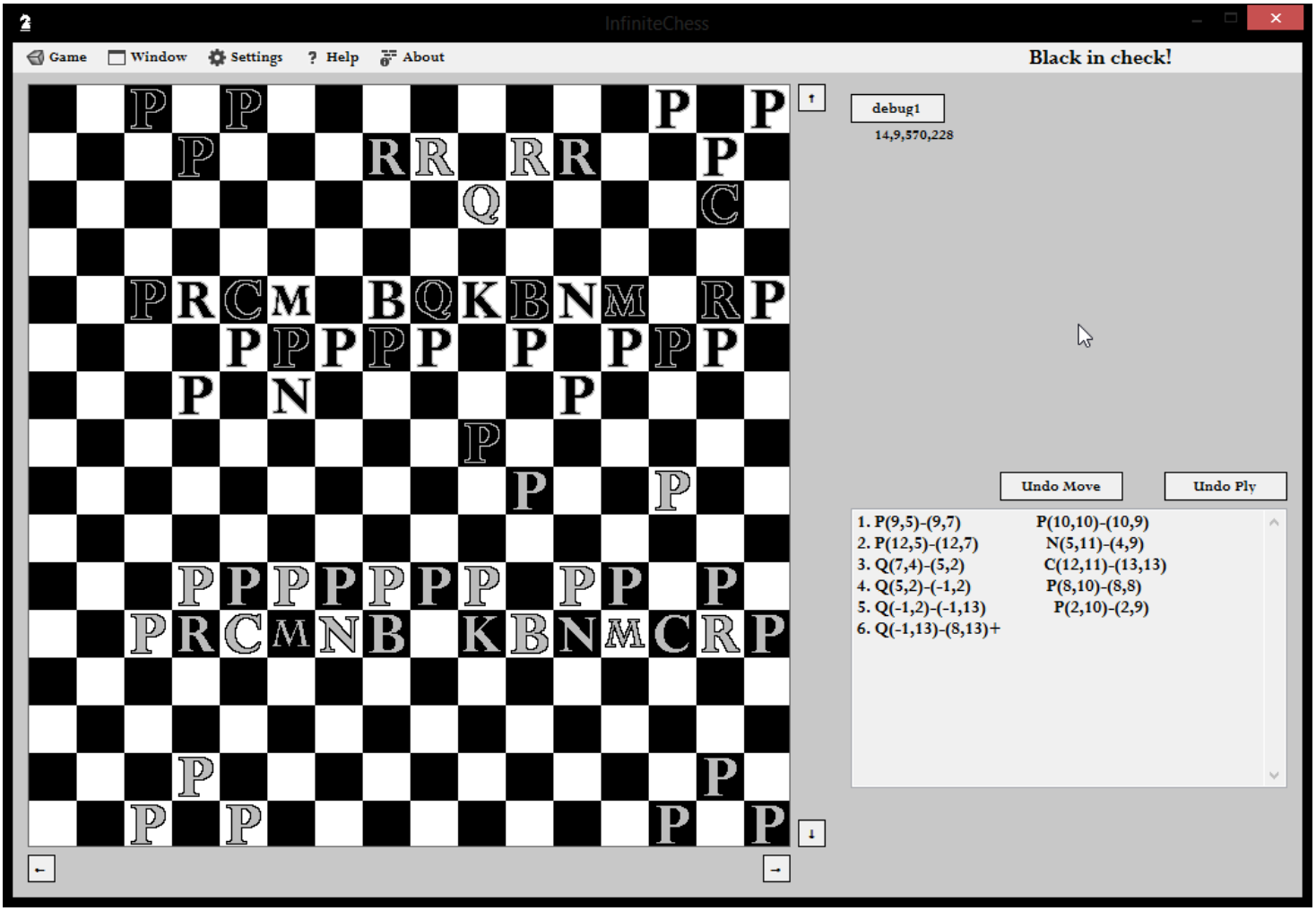
Conveniently enough, there is also an OpenFileDialog, so I just need to get the result from this and parse it. I will use the following code to get the data into a readable format:

```
OpenFileDialog open = new OpenFileDialog();
open.Filter = "Infinite Chess Game|*.icg";
open.Title = "Open Game";
open.ShowDialog();
string data = "";
if (open.FileName != "") {
    using (StreamReader sr = new StreamReader(open.FileN
    {
        data = sr.ReadToEnd();
        sr.Close();
    }
}
string[] data_pieces = data.Split('|')[0].Split(';');
string[] data_history = data.Split('|')[1].Split(';');
string[] data_state = data.Split('|')[2].Split(';');
```

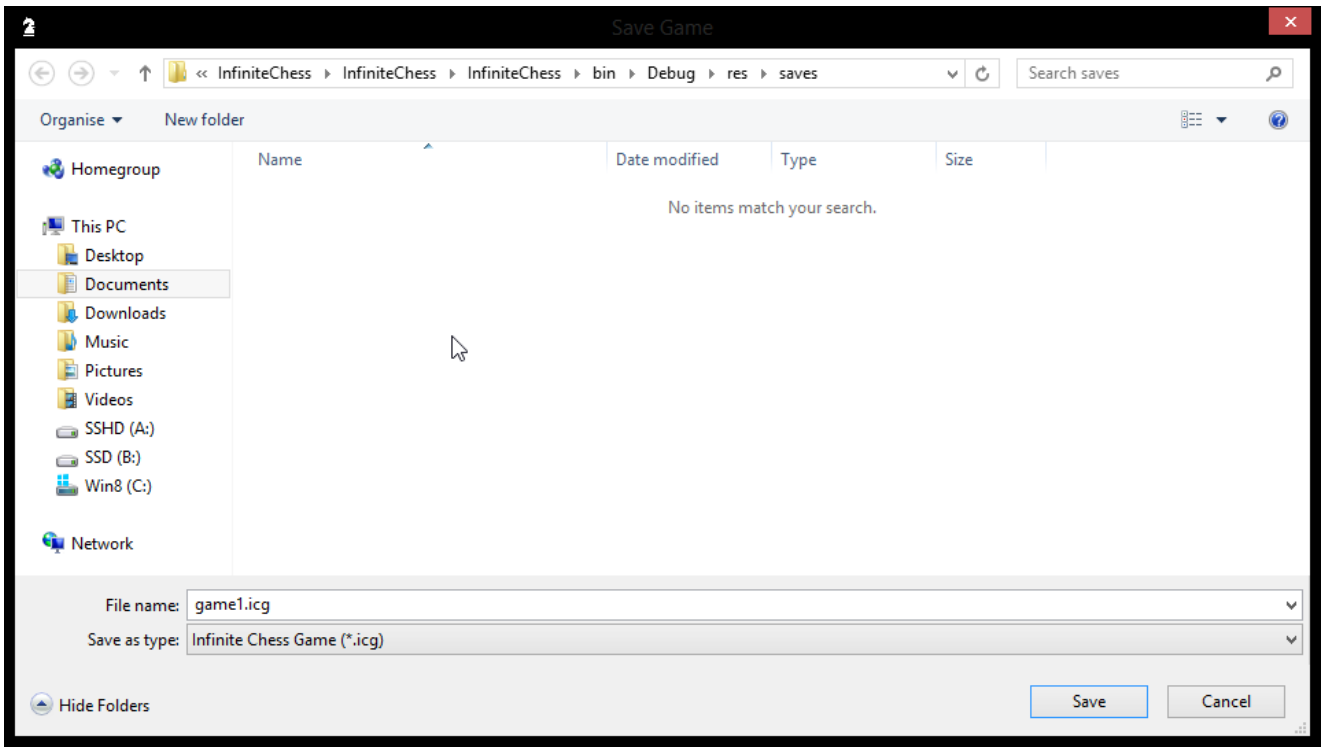
I now have three string arrays which contain everything I need. It is now just a matter of setting all the variables to the appropriate values:

```
List<Piece> piecesLoad = new List<Piece>();
bounds = new int[4];
board = new List<Square>();
origin = new int[] { 0, sf * (size[1] - 1) };
state = (GameState)int.Parse(data_state[4]);
for (int i = 0; i < 4; i++) {
    bounds[i] = int.Parse(data_state[i]);
}
InitialiseBoard();
foreach (string s in data_pieces) {
    if (s == "") continue;
    string[] p = s.Split(',');
    PieceType t = typeFromPrefix(p[0]);
    Square sq = GameContainer.findSquareByIndex(int.Parse(p[1]), int.Parse(p[2]));
    PieceColour c = p[3] == "WHITE" ? PieceColour.WHITE : PieceColour.BLACK;
    bool pd = bool.Parse(p[4]);
    int av = int.Parse(p[5]);
    piecesLoad.Add(new Piece(t, sq, c, pd, av));
}
InitialisePieces(piecesLoad);
history.setMoves(data_history.ToList());
```

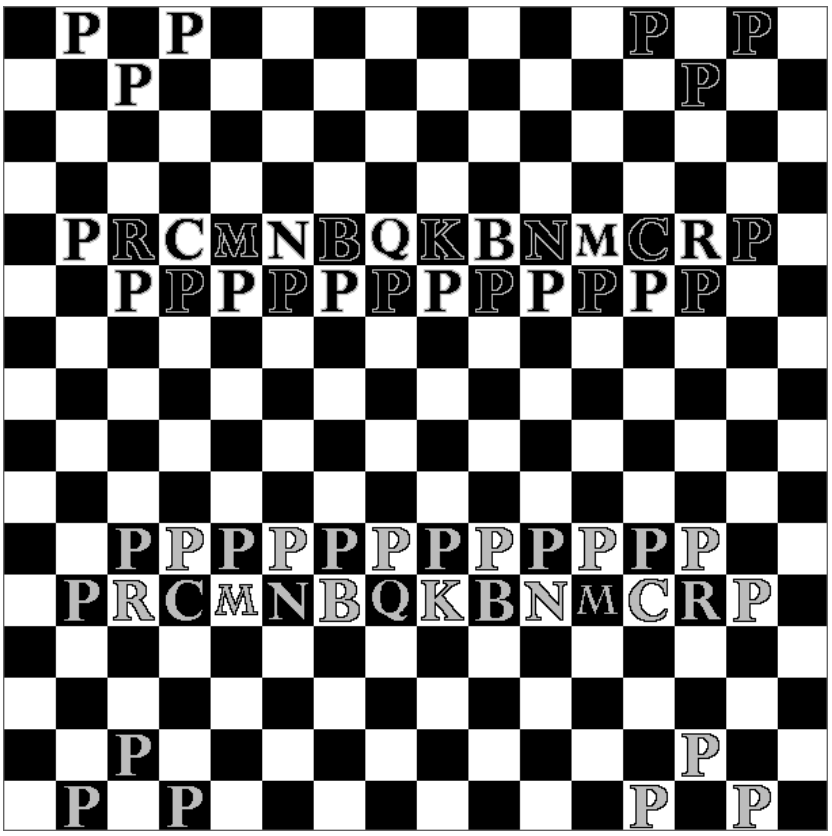
To test this, I have made up the following scenario:



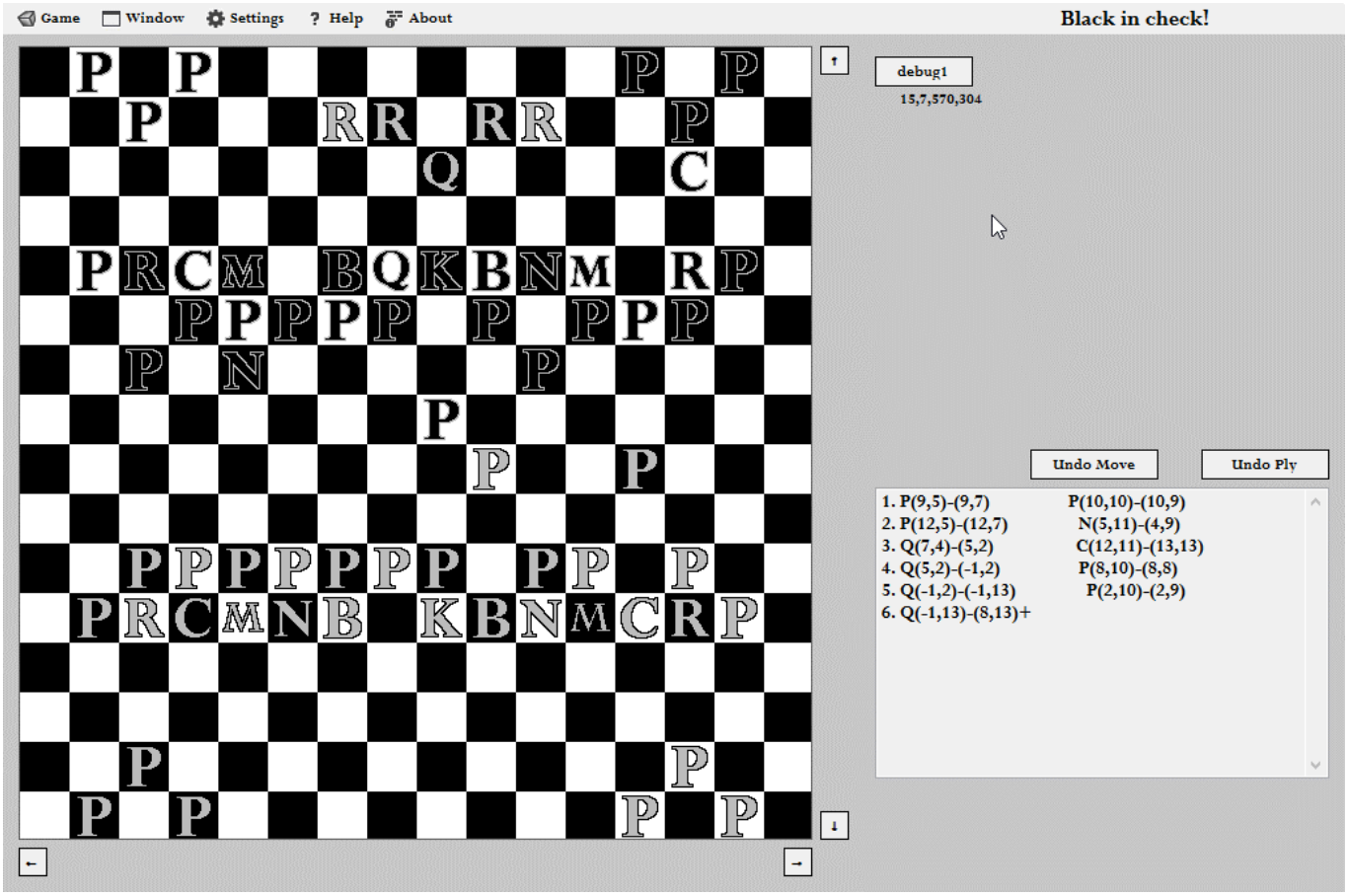
I will save this game:



Create a new game:



And then load:



The board, history and game state were all correctly loaded. I was able to continue playing and undo moves.

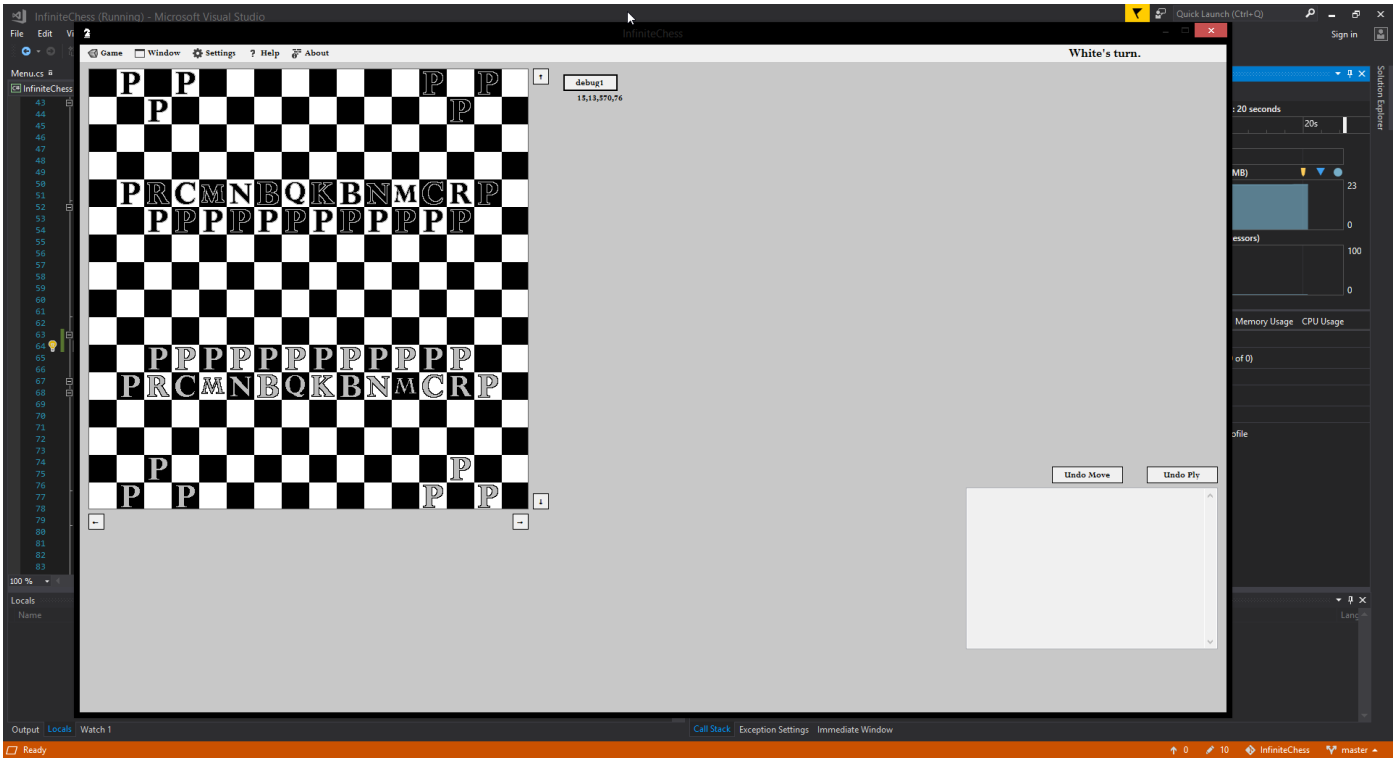
Resolution

The last feature I want to add is two different resolution settings, one for 720p and one for 1080p. Currently, the game is the correct size for a 720p screen, so all I need to do is resize all the controls appropriately when the 1080p option is selected.

First, I will need a variable to hold this setting:

```
public static bool is1080 = false;
```

Currently, the size of the window is 1044x720, which is for 720p monitors. For 1080p, 1600x960 seems like an appropriate size:



This gives me plenty of room to resize components. Before I do that, I will add the ability to change the size of the window using the menu setting. First, I will add the following line to `InitialiseStyle()`:

```
Size = is1080 ? new Size(1600, 960) : new Size(1040,720);
```

Now I can add the code for the resolution menu item:

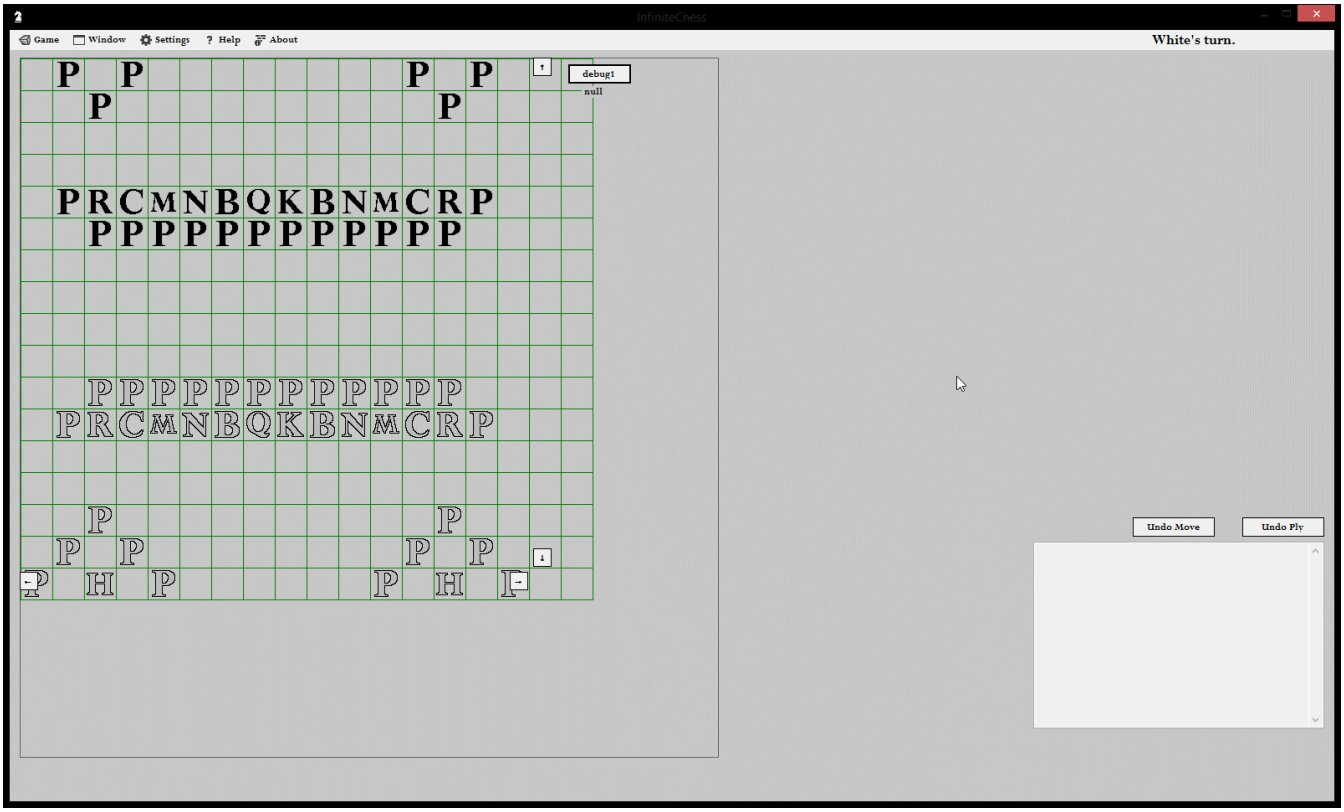
```
private void menu_window_res_720_Click(object sender, EventArgs e)
{
    setResolution(false);
}
private void menu_window_res_1080_Click(object sender, EventArgs e)
{
    setResolution(true);
}
private void setResolution(bool b) {
    is1080 = b;
    menu_window_res_720.Checked = !b;
    menu_window_res_1080.Checked = b;
    InitialiseStyle();
}
```

All this does is check and uncheck the menu items appropriately when they are clicked, and then call `InitialiseStyle`. For now, all `InitialiseStyle` will do is resize the board, so I will need to add more code to it to change some other properties.

The most important thing, of course, is the board itself. There is little point in having a larger window if no more squares can be seen. This means I will need to change the number of squares that can be seen when the resolution increases. The background graphic I am using is a fixed size, so for now I will replace it with manually drawn gridlines, and then later I will create a second graphic for the increased resolution. I will need to change the size of the component `boardPanel`, and then the variable `size` to begin with:

```
Size = is1080 ? new Size(1600, 960) : new Size(1040, 720);
size = is1080 ? new int[] { 22, 22 } : new int[] { 16, 16 };
boardPanel.Size = new Size(size[0]*sf, size[1]*sf);
```

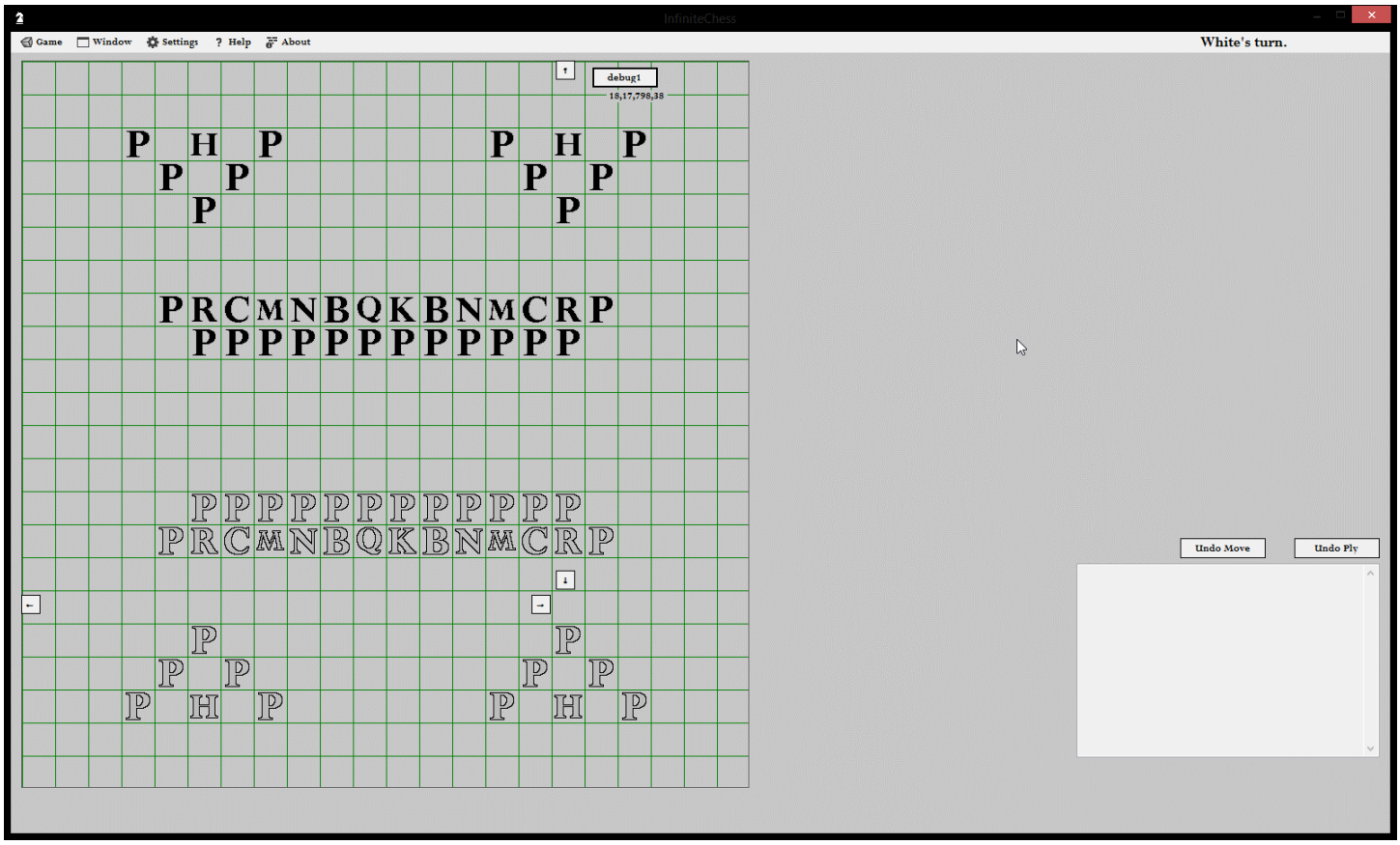
Now I can test it out. I will use the menu setting and select the 1080p option:



I can see the pieces that are normally not visible in the smaller size, but the board hasn't grown at all (shown by the green gridlines). This is because I did not update `bounds`, which is the variable used by the game to decide which squares to create. Additionally, I will want the pieces to be centred, so I will need to change `origin` as well. To do this, I will just use the scroll functions I have already written. Since these already handle checking if `bounds` need to be updated and updates the positions of every square. I need to scroll right and down to make sure that enough squares are generated, and then scroll back to centre the board. I need to do all these things in the correct order as well, otherwise the game will be attempting to scroll to squares that don't exist:

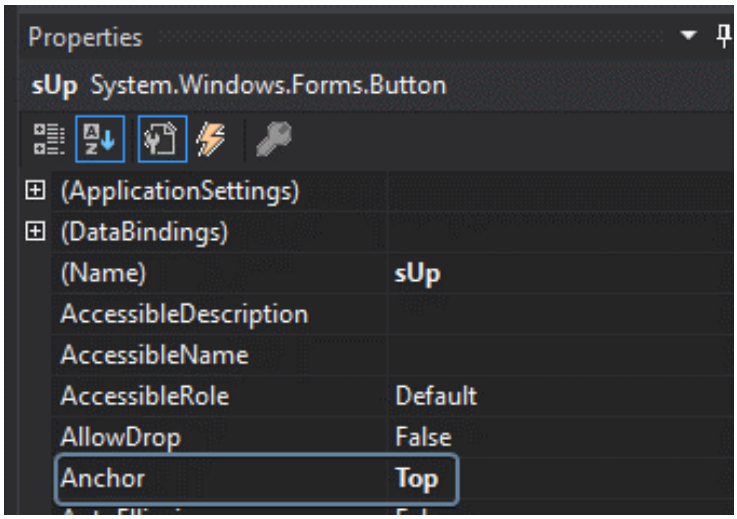
```
int s = scrollMultiplier;
Size = is1080 ? new Size(1600, 960) : new Size(1040, 720);
if (is1080) {
    scrollMultiplier = 5;
    sLeft.PerformClick(); sUp.PerformClick();
}
size = is1080 ? new int[] { 22, 22 } : new int[] { 16, 16 };
boardPanel.Size = new Size(size[0] * sf, size[1] * sf);
if (is1080) {
    scrollMultiplier = 2;
    sRight.PerformClick(); sDown.PerformClick();
    scrollMultiplier = s;
}
```

Testing it out:

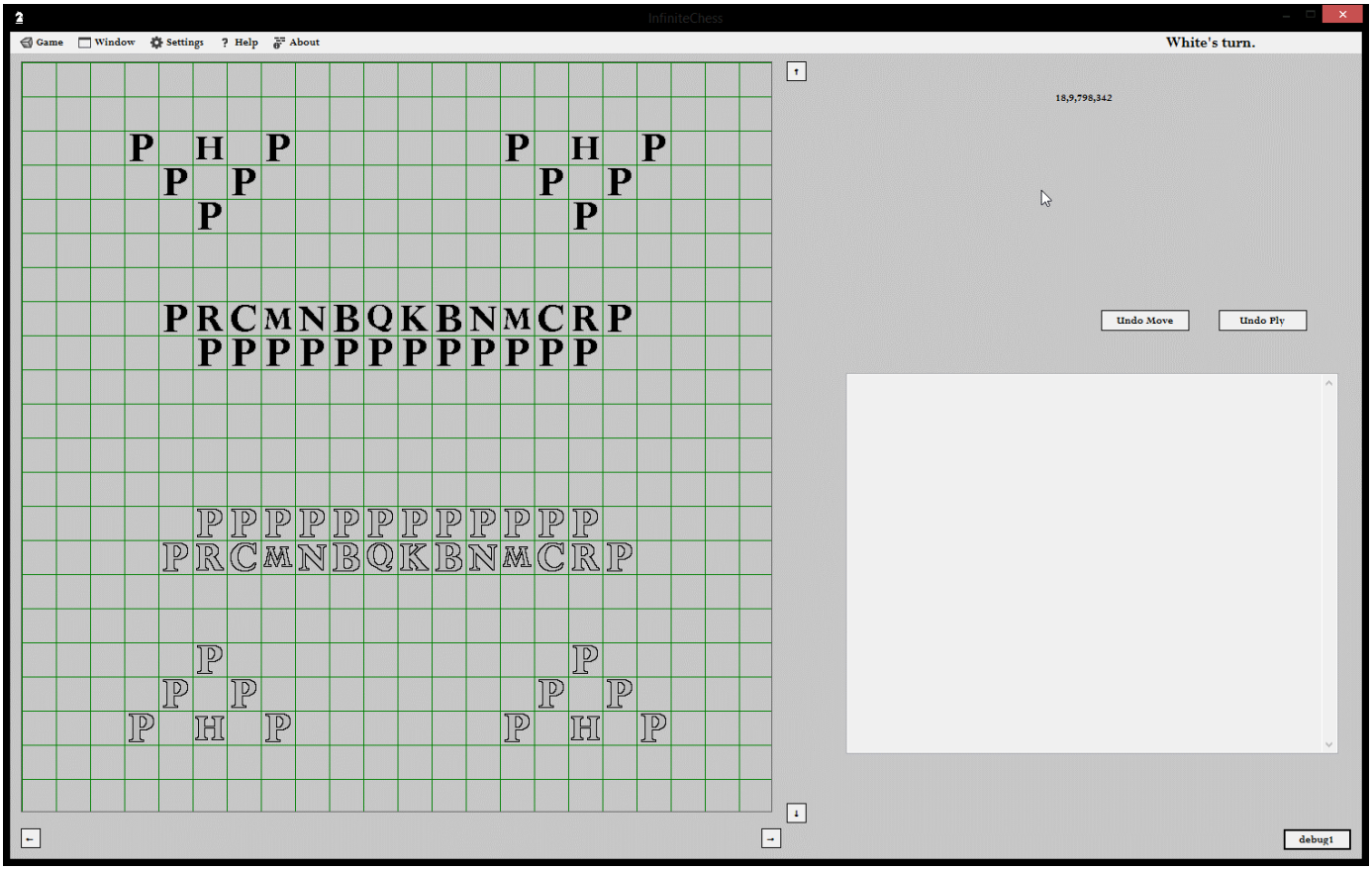


All the squares that should be on the board seem to be present, and it is centred.

The buttons are not in the correct place anymore, so I need to change the locations of those. Fortunately, visual studio allows me to anchor components to the edges of the window. This means I can anchor these buttons to the right and bottom edges of the window, which should keep them in the correct place relative to the board:



I can apply the same to the other relevant components of the board, and this is the result:

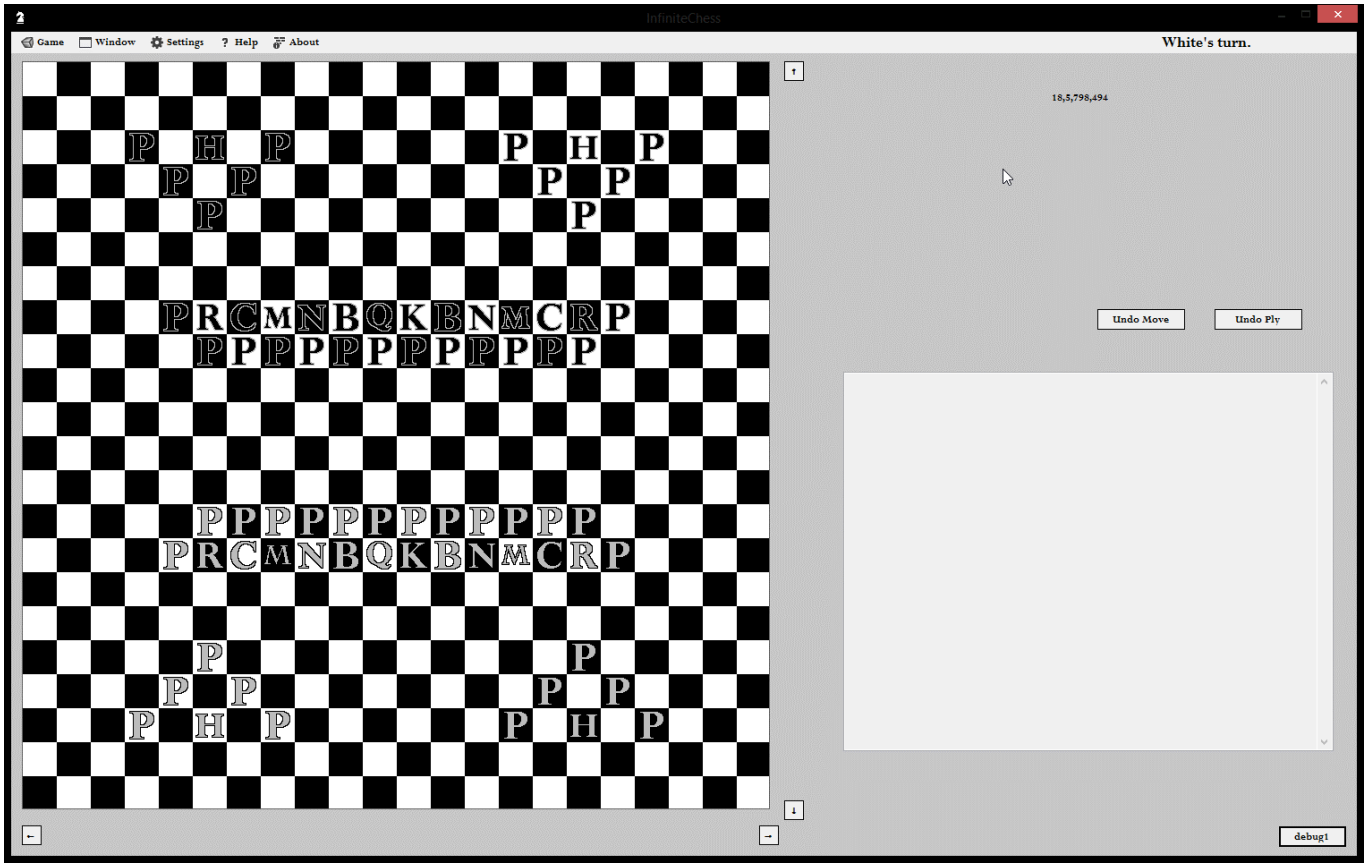


Now I just need to put the board graphic back in. I will create another graphic for the new 22x22 board and display that when necessary:

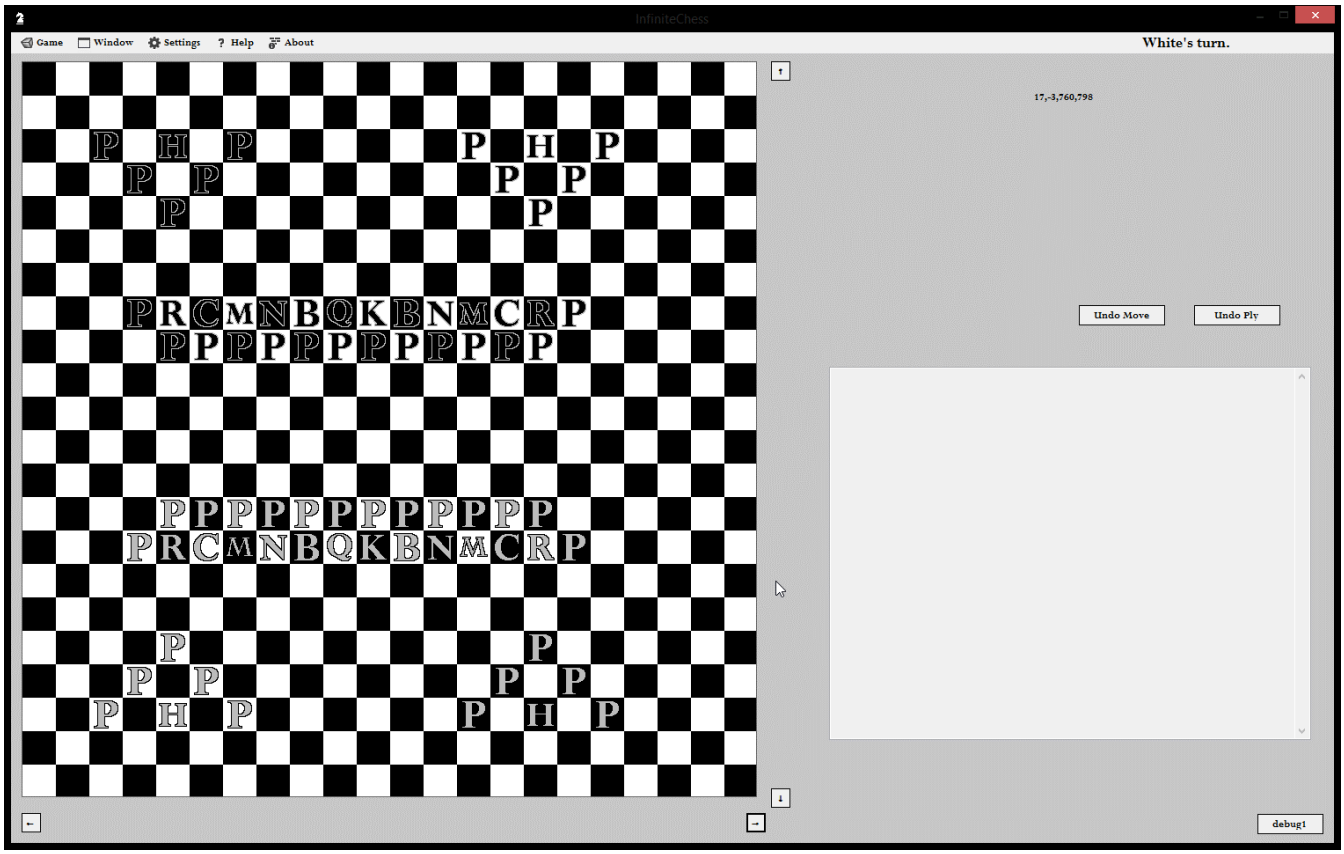
```
int boardPolarity = (origin[0] / sf + origin[1] / sf) % 2;
g.DrawImage(
    new Bitmap(
        new Bitmap($"res/image/{boardPolarity.ToString()}board{size[0].ToString()}.png"),
        new Size(sf * size[0], sf * size[1])), 0, 0
    );
```

`boardPolarity` is a variable which keeps track of which board graphic to use, since there is one with a black square in the bottom left and one with a white square in the bottom left. I have then named my image files in a way that makes it easy to decide which board to display using an interpolated string, as seen above.

Now switching to 1080p mode looks like this:



And scrolling once to the right:



Each piece is on the same colour square after the scroll as before it, which is the expected behaviour.

One issue I have noticed is that when the resolution is set to 1080p right after the program starts, the bottom of the window will be below the screen. This then causes part of the board to not render properly, so it once the window is moved back into view, the board will not be completely rendered until something happens which explicitly redraws the board (scrolling, moving a piece etc.). To solve this, I will set the Y coordinate of the window to 60 when the resolution changes to 1080p.

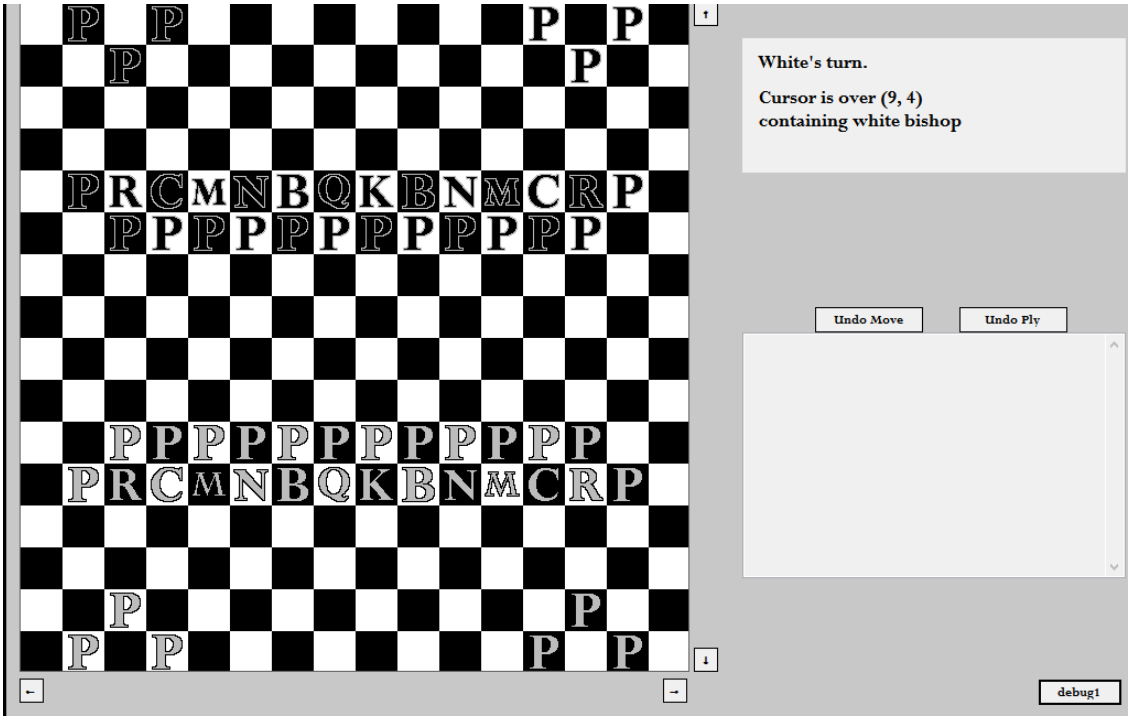
Application Polish

I have now implemented all the features that I plan to, so now it is time to add some polish to the game to make it more presentable as a product.

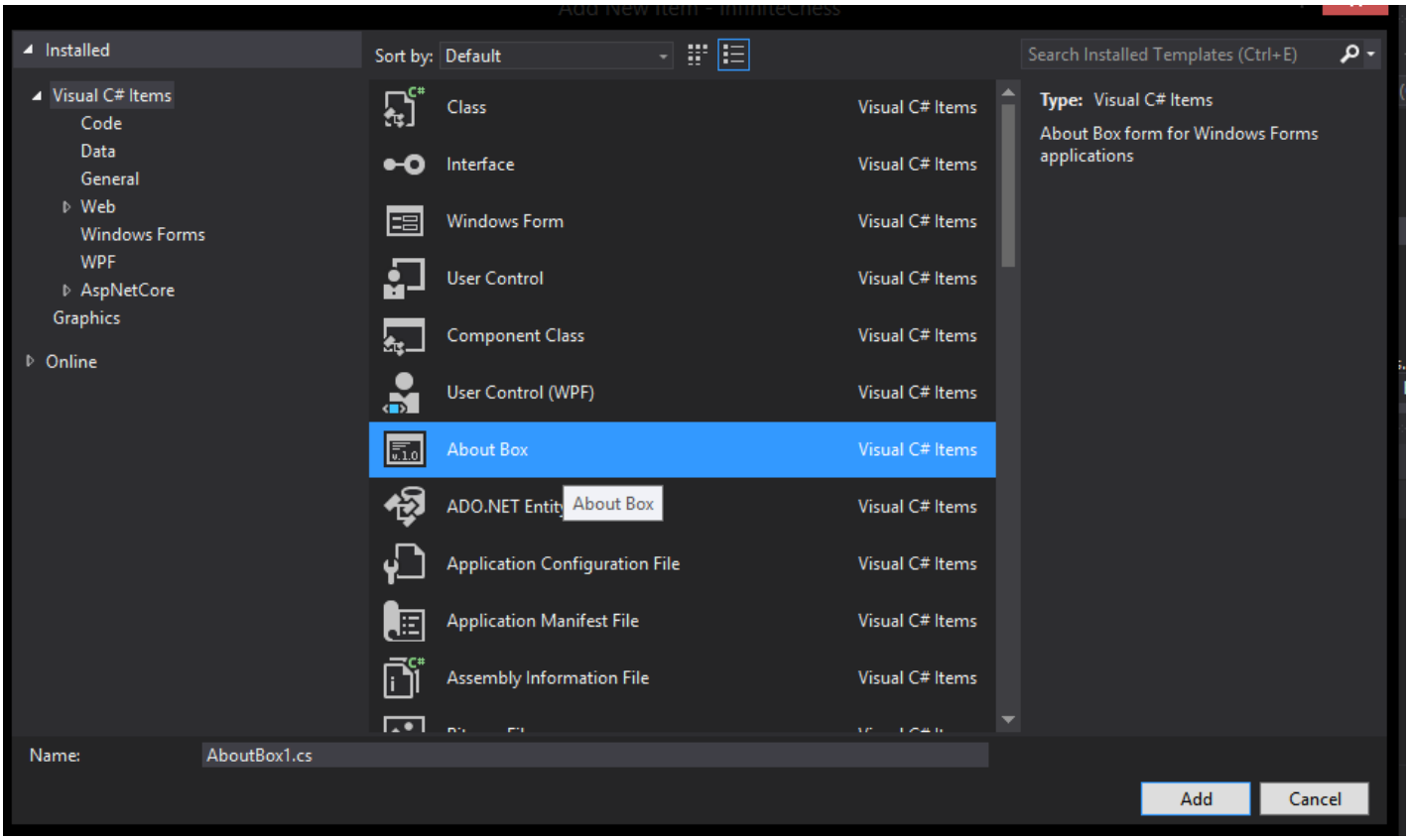
First, I will improve the debug label currently displaying the square under the cursor. I will use it for to display just the index of the square the cursor is under, and also add a label which explains its function to the user:

```
protected override void OnMouseMove(MouseEventArgs e)
{
    c = getForm<Chess>();
    Square cursorSquare = findSquareByCoords(e.X, e.Y);
    string s =
        $"Cursor is over ({cursorSquare?.indexX.ToString()}, {cursorSquare?.indexY.ToString()})";
    Piece p = pieces.Find(q => q.square == cursorSquare) ?? null;
    if (p != null) {
        s +=
            $"\ncontaining {p.colour.ToString().ToLower()} {p.type.ToString().ToLower()}";
    }
    c.cursorLabel.Text = s;
```

The label will display the index of the square it is over and will also display the colour and name of any the piece the cursor is over, if there is one.



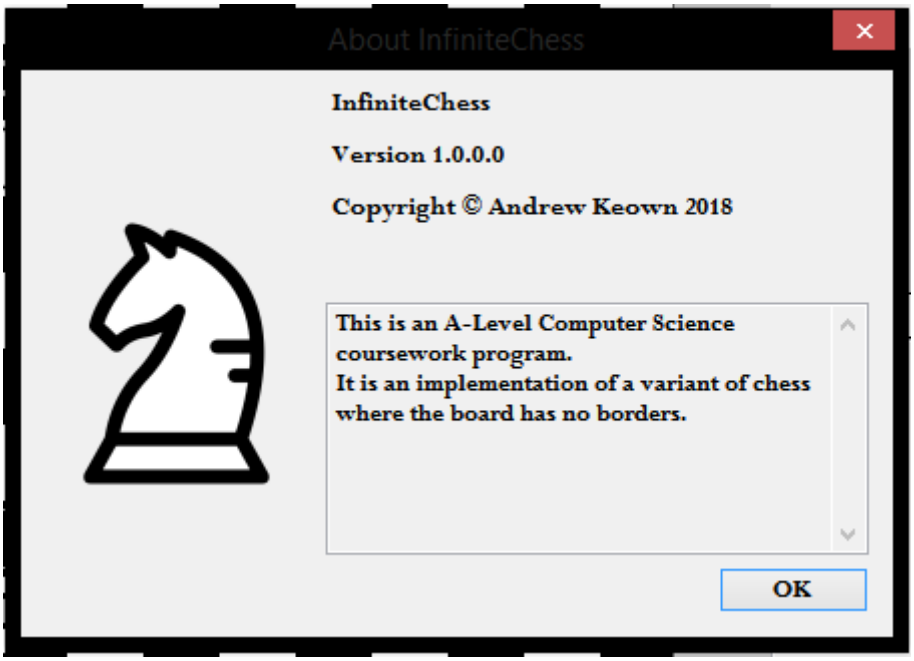
Next, I will add an About dialog for the game. This will give the game a more professional feel. Visual Studio provides a template for these:



It fills in the dialog with some text based on project settings, such as the project name and version. I have added a description and my own name into the box, and also added a picture.

I can then call it with the menu item:

```
private void menu_about_about_Click(object sender, EventArgs e)
{
    About a = new About();
    a.ShowDialog();
}
```

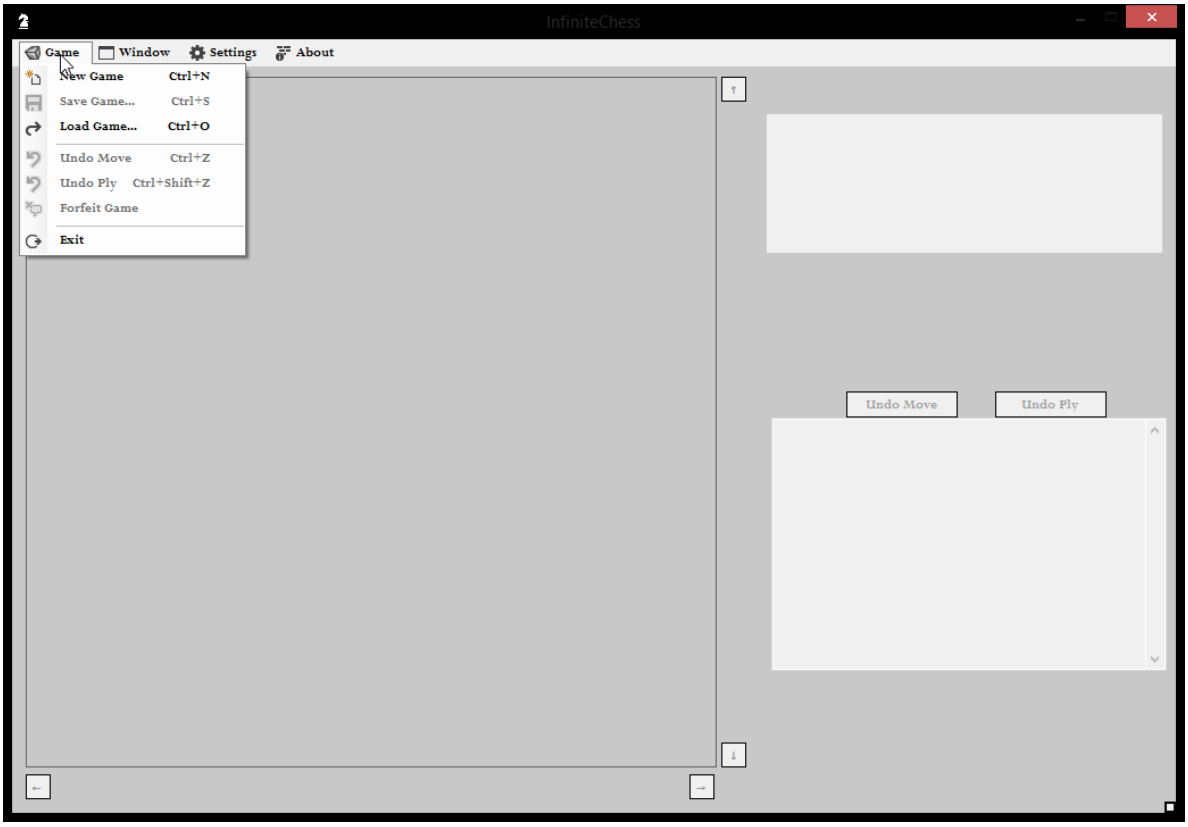


When the program is opened, a game is not immediately generated; the new game button must be played. Before the game has been generated, pressing a button that relies on the game being there, such as scrolling the board or undoing a move, could cause an exception, which would crash the program. To fix this, I will disable all buttons that can only function when the game is generated before new game is pressed:

```
public void InitialiseButtons(bool b) {
    sUp.Enabled = b;
    sDown.Enabled = b;
    sRight.Enabled = b;
    sLeft.Enabled = b;
    undo1.Enabled = b;
    undo2.Enabled = b;
    menu_game_undo.Enabled = b;
    menu_game_undo2.Enabled = b;
    menu_game_save.Enabled = b;
    menu_game_forfeit.Enabled = b;
    menu_setting_scroll_scroll.Enabled = b;
    menu_setting_undo.Enabled = b;
    history.Enabled = b;
}
```

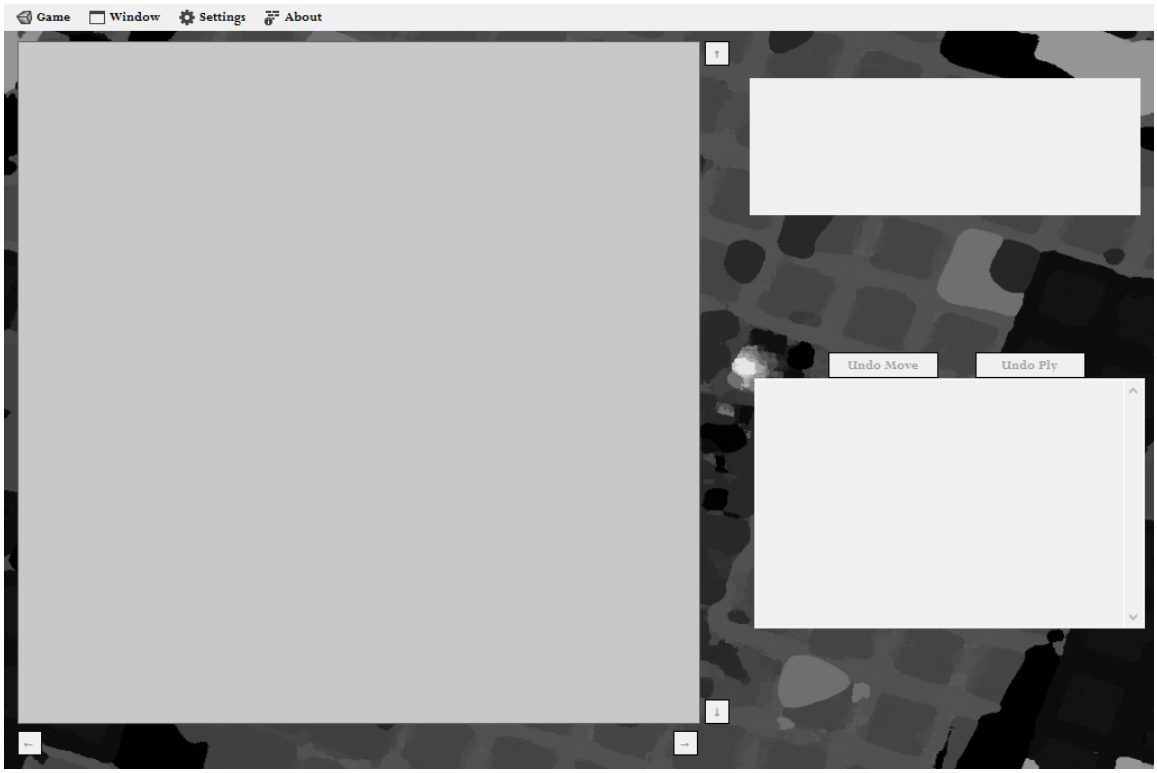
```
public Chess()
{
    InitializeComponent();
    InitialiseStyle();
    InitialiseButtons(false);
    //Init();
}
```

Now the game appears in the following way before new game is pressed:

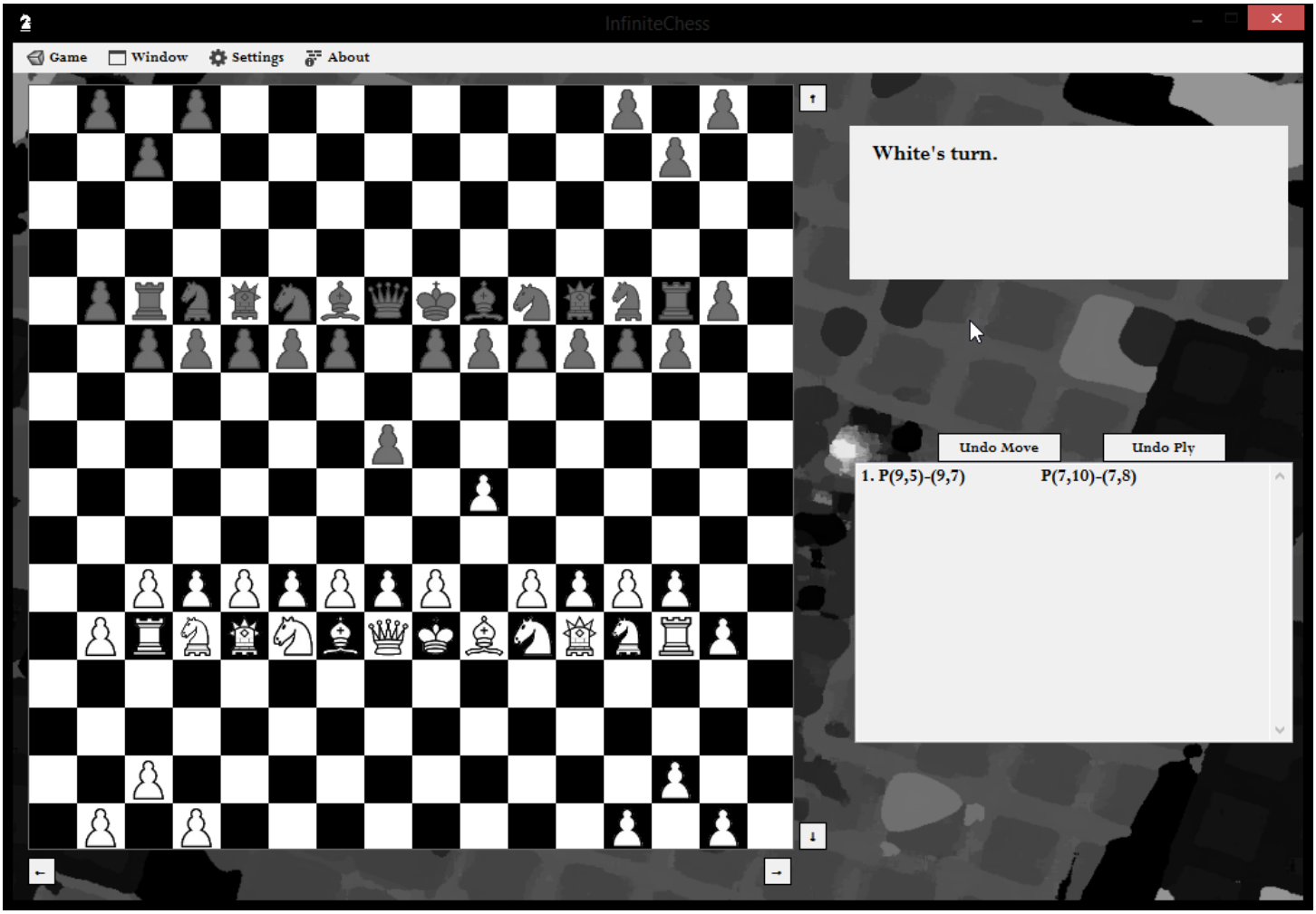


This should prevent any errors from the game trying to use features that haven't been initialised yet.

The graphical appearance of the game is important, so now is the time to finish the graphics. First, I will add a background image to replace the solid grey:

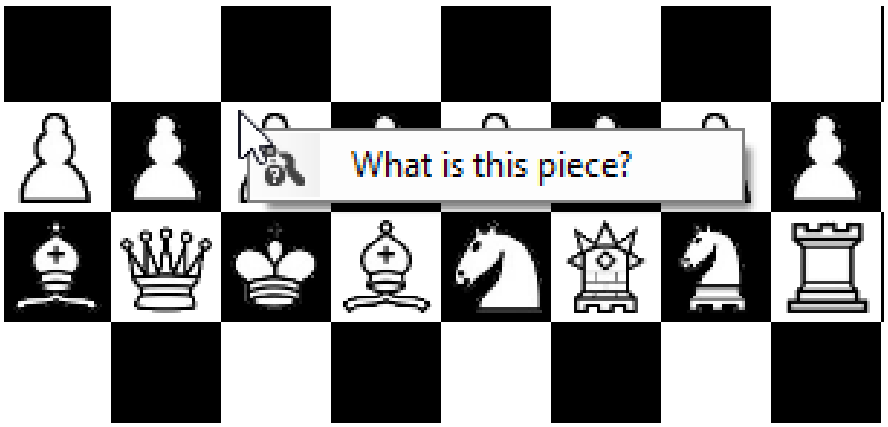


I need to replace the piece graphics. Currently they are letters, which is not what I want in the final game. I have used the icons from Chess Variants, since this is the only place I could find an icon for the mann, chancellor and hawk:



The game now looks a lot more professional and polished than before.

Earlier I added a help button to the menu strip. The purpose of this was to help users with information about the pieces that are not in regular chess. However, I have decided this is quite an inconvenient way to learn about them. Instead, I will replace the menu item with a right click menu, known as a context menu.



I will then write some text for each type of piece and display it in a message box when the context menu item is selected.

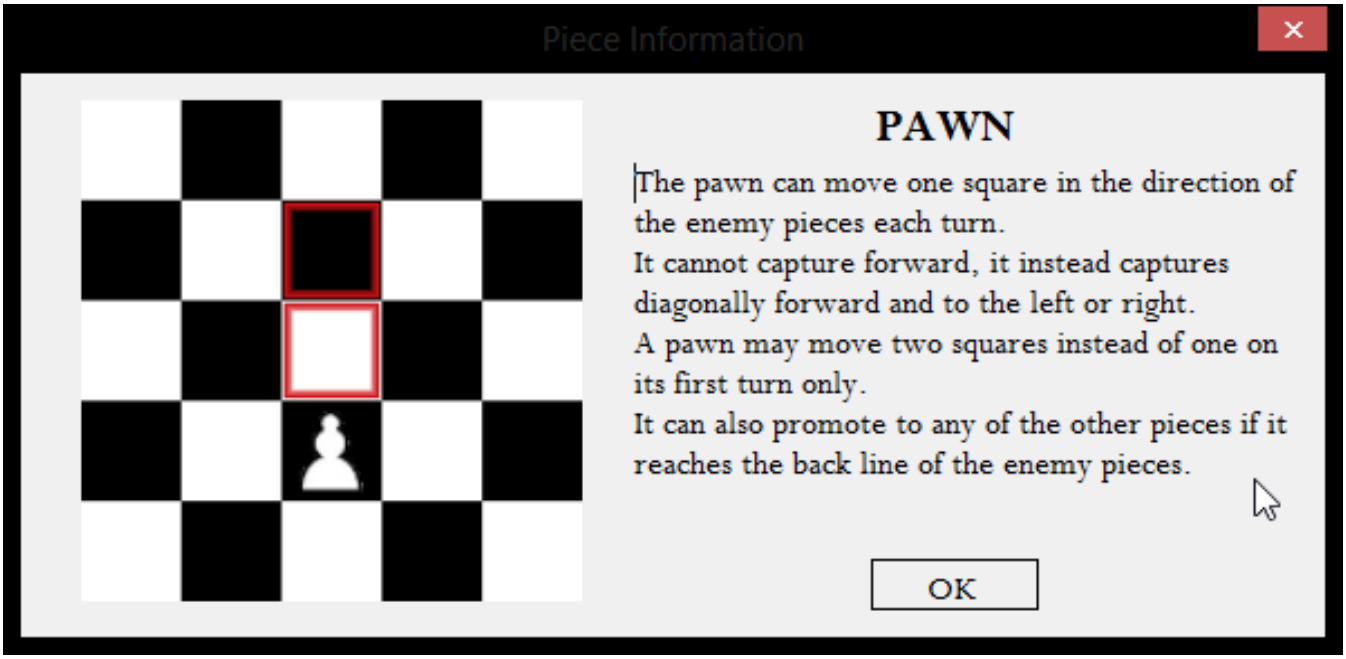
The context menu is called on right click via the following:

```
if (e.Button == MouseButtons.Right) {
    if (found == null) return;
    c.pieceContextMenu.Show(Cursor.Position);
    c.pieceContextMenu.Text = prefixFromType(found.type);
}
```

And then clicking the menu item in the context menu calls:

```
private void pieceInfoContextItem_Click(object sender, EventArgs e)
{
    string type = pieceContextMenu.Text;
    string text = File.ReadAllText($"res/help/text/{pieceContextMenu.Text}.txt");
    Bitmap image = new Bitmap($"res/help/image/{pieceContextMenu.Text}.png");
    PieceInfo p = new PieceInfo(typeFromPrefix(type).ToString(), text, image);
    p.ShowDialog();
}
```

For example, the help dialog for a pawn looks like this:



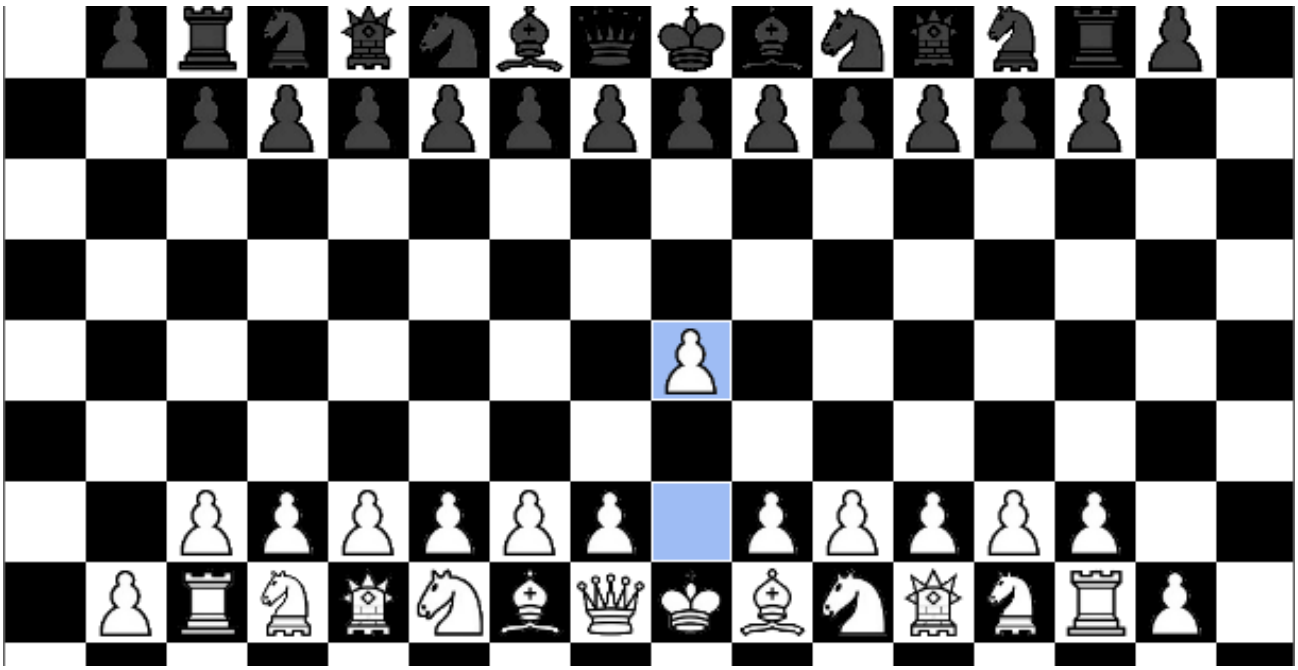
This should increase the usability and user-friendliness of the game, since a player can now find out within the game what each piece does.

The final thing I want to add is visual indicators of the last move. While the move history textually records all moves, it can be difficult for a player to look at the last move and know instantly where the other player moved. This is because there are a lot of pieces and there are only two colours on the board. Whenever a piece moves, I will draw a coloured square under the square it moved from and the square it moved to. This should make it clear what the last move was, and hopefully make the game more user friendly.

The following loop is added to `drawBoard`:

```
foreach (Square s in history.getLastMoveSquares()) {
    Color c = Color.FromKnownColor(KnownColor.CornflowerBlue);
    for (int j = 0; j < 18; j++) {
        g.DrawRectangle(new Pen(Color.FromArgb(160, c)), s.X + j + 1, s.Y + j + 1, sf - (2*j) - 3, sf - (2*j) - 3);
    }
}
```

And this produces the following result:



This makes it much clearer where the last move was. This feature also works as expected when undoing moves; the current last move is always highlighted.

Full Code

InfiniteChess.cs

```
using System;
using System.Collections.Generic;
using System.ComponentModel;
using System.Data;
using System.Drawing;
using System.Linq;
using System.Text;
using System.Threading;
using System.Windows.Forms;
using System.Diagnostics;

namespace InfiniteChess
{
    [Flags] public enum GameState { COLOUR = 0x01, MOVE = 0x02, CHECK = 0x04, WIN = 0x08,
STALE = 0x10 }

    public partial class Chess : Form
    {
        //global variables
        public static List<Square> board = Square.emptyList(); //stores all squares of the
board
        public static int[] origin = new int[2]; //coordinates of [0,0]
        public static int[] bounds = new int[4];//boundaries of the generated board
        public static int[] size = { 16, 16 }; //size of the visible board
        public static int sf = 38;

        public static List<Piece> pieces = new List<Piece>();
        public static Piece pieceMoving = null;
        public static List<Square> pieceMovingMoves = new List<Square>();
        public static Piece lastMove = null;
        public static GameState state = 0;

        public static bool movementIndicators = true;
        public static int scrollMultiplier = 1;
        public static bool opponentAI = false;
        public static int AIDIfficulty = 0;
        public static bool is1080 = false;

        public Chess()
        {
            InitializeComponent();
            InitialiseStyle();
            InitialiseButtons(false);
            //Init();
        }
        #region init
        public void Init()
        {
            InitialiseButtons(true);
            InitialiseVars();
            InitialiseFeatures();
            InitialiseBoard();
            InitialisePieces(Piece.IntializePieces());
        }

        public void InitialiseButtons(bool b) {
            sUp.Enabled = b;
            sDown.Enabled = b;
            sRight.Enabled = b;
            sLeft.Enabled = b;
            undo1.Enabled = b;
```

```
            undo2.Enabled = b;
            menu_game_undo.Enabled = b;
            menu_game_undo2.Enabled = b;
            menu_game_save.Enabled = b;
            menu_game_forfeit.Enabled = b;
            menu_setting_scroll_scroll.Enabled = b;
            menu_setting_undo.Enabled = b;
            history.Enabled = b;
        }

        public void InitialiseVars()
        {
            board = Square.emptyList();
            if (is1080)
            {
                origin = new int[] { 114, 684 };
                bounds = new int[] { -4, size[0] + 1, -4, size[1] + 1 };
            }
            else
            {
                bounds = new int[] { -1, size[0] + 1, -1, size[1] + 1 };
                origin = new int[] { 0, sf * (size[1] - 1) };
            }

            pieceMoving = null;
            pieceMovingMoves = Square.emptyList(); ;
            lastMove = null;
            state = 0;
        }

        public void InitialiseStyle()
        {
            Color highlight = Color.FromKnownColor(KnownColor.Control);
            BackColor = Color.FromArgb(200, 200, 200);
            foreach (Control c in Controls)
            {
                if (c.GetType() == typeof(Button))
                {
                    Button b = c as Button;
                    b.FlatStyle = FlatStyle.Flat;
                    b.BackColor = highlight;
                    b.FlatAppearance.BorderColor = Color.Black;
                    b.FlatAppearance.BorderSize = 1;
                    b.FlatAppearance.MouseDownBackColor = Color.LightGray;
                    b.FlatAppearance.MouseOverBackColor = Color.FromArgb(224, 224, 224);
                }
                c.Font = new Font("Perpetua", 9, FontStyle.Bold);
                c.ForeColor = Color.Black;
            }
            stateLabel.Font = new Font("Perpetua", 13, FontStyle.Bold);
            cursorLabel.Font = new Font("Perpetua", 13, FontStyle.Bold);
            menu.ForeColor = Color.Black;
            menu.BackColor = highlight;
            history.BackColor = highlight;
            history.ForeColor = Color.Black;
            labelBack.BackColor = highlight;
            stateLabel.BackColor = highlight;
            cursorLabel.BackColor = highlight;

            int s = scrollMultiplier;
            Size = is1080 ? new Size(1520, 960) : new Size(1040, 720);
            if (is1080)
            {
                scrollMultiplier = 5;
                sLeft.PerformClick(); sUp.PerformClick();
```

```
            }
            size = is1080 ? new int[] { 22, 22 } : new int[] { 16, 16 };
            boardPanel.Size = new Size(size[0] * sf, size[1] * sf);
            if (is1080)
            {
                scrollMultiplier = 5;
                sRight.PerformClick(); sDown.PerformClick();
                scrollMultiplier = s;
                history.Size = new Size(548, 424);
                history.Location = new Point(930, 380);
                history.Font = new Font("Perpetua", 15, FontStyle.Bold);
            }
            else
            {
                history.Size = new Size(348, 223);
                history.Location = new Point(668, 333);
                history.Font = new Font("Perpetua", 11, FontStyle.Bold);
            }
            stateLabel.Text = "";
            cursorLabel.Text = "";
        }

        //create the logical board
        public void InitialiseBoard()
        {
            for (int i = bounds[0]; i < bounds[1] + 1; i++)
            { //columns
                for (int j = bounds[2]; j < bounds[3] + 1; j++)
                { //rows
                    board.Add(new Square
                    {
                        X = origin[0] + sf * i,
                        Y = origin[1] - sf * j,
                        indexX = (short)i,
                        indexY = (short)j
                    });
                }
            }
        }

        public void InitialisePieces(List<Piece> ps)
        {
            pieces = ps;
            drawBoard();
        }

        public void InitialiseFeatures()
        {
            history.moves.Clear();
            history.Text = "";
        }

        #endregion
        #region values
        public static void updateValues()
        {
            pieces.ForEach(q => q.addedValue = 0);
            foreach (Piece p in pieces)
            {
                int colour = p.colour == PieceColour.WHITE ? 1 : -1;
                var far = from q in pieces
                          where Math.Abs(p.square.indexX - q.square.indexX) < 4
                          && Math.Abs(p.square.indexY - q.square.indexY) < 4
                          && q.colour == p.colour
                          select q;
```

```
                if (far.Count() == 1) { p.addedValue -= 4000 * colour; }
                if (far.Count() == 2) { p.addedValue -= 100 * colour; }

                switch (p.type)
                {
                    case PieceType.PAWN:
                        {
                            var query = from q in pieces
                                        where q.square.indexY == p.square.indexY + colour
                                        && Math.Abs(q.square.indexX - p.square.indexX) == 1
                                        select q;
                            foreach (Piece t in query)
                                t.addedValue += 200 * (t.colour == PieceColour.WHITE ? 1 :
-1);
                            if (colour == 1)
                            {
                                if (p.square.indexY == 7) p.addedValue += 400;
                                if (p.square.indexY == 8) p.addedValue += 1000;
                                if (p.square.indexY == 9) p.addedValue += 1500;
                                if (p.square.indexY == 10) p.addedValue += 2500;
                            }
                            else
                            {
                                if (p.square.indexY == 8) p.addedValue -= 400;
                                if (p.square.indexY == 7) p.addedValue -= 1000;
                                if (p.square.indexY == 6) p.addedValue -= 1500;
                                if (p.square.indexY == 5) p.addedValue -= 2500;
                            }
                            break;
                        }
                    case PieceType.MANN:
                        {
                            var query = from q in pieces
                                        where Math.Abs(q.square.indexY - p.square.indexY) <
2
                                        && Math.Abs(q.square.indexX - p.square.indexX) < 2
                                        && q.colour == p.colour
                                        select q;
                            if (query.Count() > 0) p.addedValue += 1000 * colour;
                            break;
                        }
                    case PieceType.ROOK:
                        {
                            var query = from q in pieces
                                        where (p.square.indexX == q.square.indexX
                                        || p.square.indexY == q.square.indexY)
                                        && q.colour != p.colour
                                        select q;
                            var king = from t in query
                                       where t.type == PieceType.KING
                                       select t;
                            if (query.Count() > 0) p.addedValue += 2000 * colour;
                            if (king.Count() > 0) p.addedValue += 2000 * colour;
                            break;
                        }
                    case PieceType.CHANCELLOR: { goto case PieceType.ROOK; }
                    case PieceType.BISHOP:
                        {
                            var query = from q in pieces
                                        where (p.square.indexX - q.square.indexX
                                        == p.square.indexY - q.square.indexY)
                                        && q.colour != p.colour
                                        select q;
                            var king = from t in query
                                       where t.type == PieceType.KING
```

```
                                    select t;
                            if (query.Count() > 0) p.addedValue += 1500 * colour;
                            if (king.Count() > 0) p.addedValue += 1500 * colour;
                            break;
                        }
                    case PieceType.QUEEN:
                        {
                            var query = from q in pieces
                                        where (p.square.indexX - q.square.indexX
                                        == p.square.indexY - q.square.indexY)
                                        || (p.square.indexX == q.square.indexX
                                        || p.square.indexY == q.square.indexY)
                                        && q.colour != p.colour
                                        select q;
                            var king = from t in query
                                       where t.type == PieceType.KING
                                       select t;
                            if (query.Count() > 0) p.addedValue += 2500 * colour;
                            if (king.Count() > 0) p.addedValue += 2500 * colour;
                            break;
                        }
                }
                if (colour == 1) p.addedValue = Math.Max(p.addedValue - (1000 - 10 *
AIDIfficulty), 0);
                else p.addedValue = Math.Min(p.addedValue + (1000 - 10 * AIDIfficulty), 0);

            }
        }
        #endregion
        #region util
        public void drawBoard()
        {
            if (!history.Enabled) { return; }
            Graphics g = boardPanel.CreateGraphics();
            g.Clear(Color.FromArgb(200, 200, 200));
            int boardPolarity = (origin[0] / sf + origin[1] / sf) % 2;
            g.DrawImage( new Bitmap(
                    new
Bitmap($"res/image/board/{boardPolarity.ToString()}board{size[0].ToString()}.png"),
                    new Size(sf * size[0], sf * size[1])), 0, 0
                );
           foreach (Square s in history.getLastMoveSquares()) {
                Color c = Color.FromKnownColor(KnownColor.CornflowerBlue);
                for (int j = 1; j < 18; j++) {
                    g.DrawRectangle(new Pen(Color.FromArgb(160 - (2*j), c)), s.X + j + 1,
s.Y + j + 1, sf - (2*j) - 3, sf - (2*j) - 3);
                }
            }
            foreach (Piece p in pieces)
            {
                g.DrawImage(new Bitmap(p.icon, new Size(sf - 6, sf - 6)), p.square.X + 3,
p.square.Y + 3);
            }
            g.Dispose();
            if (state.HasFlag(GameState.MOVE)) { boardPanel.drawMoves(pieceMoving); }
            stateLabel.Text = $"{parseState(state)}";
        }
        public void updateSquares(int amount, bool isX, object sender)
        {
            origin[isX ? 0 : 1] += sf * amount;
            if (isX) { board.ForEach(s => s.X += sf * amount); }
            else { board.ForEach(s => s.Y += sf * amount); }
        }

        public static int findLargest(int[] i)
```

```
        {
            int j = int.MinValue;
            foreach (int k in i) { if (k > j) j = k; }
            return j;
        }
        public static int checkSquareForPiece(Square s, bool includeKings, PieceColour c)
        {
            //foreach (Piece p in pieces) {
            Piece p;
            for (int i = 0; i < pieces.Count; i++)
            {
                p = pieces[i];
                if (p.square == s)
                {
                    if (p.type == PieceType.KING && !includeKings) return 2;
                    if (c != p.colour)
                        return 1;
                    else return 2;
                }
            }
            return 0;
        }

        private void begin_Click(object sender, EventArgs e)
        {
            drawBoard();
        }
        private void debug3_Click(object sender, EventArgs e)
        {

        }
        private void mouseMove(object sender, MouseEventArgs e)
        {
            Point loc = e.Location;
            Point boardCorner = boardPanel.Location;
            Point oppositeCorner = new Point(
                boardPanel.Location.X + boardPanel.Size.Width,
                boardPanel.Location.Y + boardPanel.Size.Height
                );
                cursorLabel.Text = "";
        }
        private void undo_Click(object sender, EventArgs e) => undo(1);
        private void undo2_Click(object sender, EventArgs e) => undo(2);
        private void undo(int i)
        {
            history.undoMove(i);
            drawBoard();
            if (opponentAI && state.HasFlag((GameState)1))
                AIThread.RunWorkerAsync();
        }
        public static string prefixFromType(PieceType t)
        {
            switch (t)
            {
                case PieceType.BISHOP: return "B";
                case PieceType.CHANCELLOR: return "C";
                case PieceType.HAWK: return "H";
                case PieceType.KING: return "K";
                case PieceType.KNIGHT: return "N";
                case PieceType.MANN: return "M";
                case PieceType.NONE: return "Z";
                case PieceType.PAWN: return "P";
                case PieceType.QUEEN: return "Q";
                case PieceType.ROOK: return "R";
            }
```

```
            return "#";
        }
        public static PieceType typeFromPrefix(string c)
        {
            switch (c)
            {
                case "B": return PieceType.BISHOP;
                case "C": return PieceType.CHANCELLOR;
                case "H": return PieceType.HAWK;
                case "K": return PieceType.KING;
                case "N": return PieceType.KNIGHT;
                case "M": return PieceType.MANN;
                case "Z": return PieceType.NONE;
                case "P": return PieceType.PAWN;
                case "Q": return PieceType.QUEEN;
                case "R": return PieceType.ROOK;
            }
            return PieceType.NONE;
        }
        public static string parseState(GameState g)
        {
            string colour = g.HasFlag((GameState)1) ? "Black" : "White";
            string final = $"{colour}'s turn.";
            if (g.HasFlag((GameState)4)) { final = $"{colour} in check!"; }
            if (g.HasFlag((GameState)2))
            {
                if (pieceMovingMoves.Count == 0)
                    final = $"That piece cannot move!";
                else
                    final = $"{colour} moving
{pieceMoving.type.ToString().ToLowerInvariant()}.";
                if (g.HasFlag((GameState)1) && opponentAI) { final = "AI Moving..."; }
            }
            if (g.HasFlag((GameState)8)) { final = $"{colour} has won!"; }
            if (g.HasFlag((GameState)16)) { final = "Stalemate"; }
            return final;
        }
        private void AIThread_DoWork(object sender, DoWorkEventArgs e)
        {
            boardPanel.AIThread_DoWork(sender, e);
        }

        private void AIThread_RunWorkCompleted(object sender, RunWorkerCompletedEventArgs
e)
        {
            boardPanel.AIThread_WorkCompleted(sender, e);
        }
        #endregion
        #region scrolling
        private void sUp_Click(object sender, EventArgs e)
        {
            for (int i = 0; i < scrollMultiplier; i++)
            {
                Square edge = GameContainer.findSquareByCoords(0, 0);
                updateSquares(1, false, sender);
                if (edge.indexY == bounds[3])
                {
                    bounds[3]++;
                    for (int j = bounds[0]; j <= bounds[1]; j++)
                    {
                        board.Add(new Square
                        {
                            X = origin[0] + sf * j,
                            Y = origin[1] - bounds[3] * sf,
                            indexX = (short)j,
```

```
                        indexY = (short)bounds[3]
                    });
                }
            }
        }
        drawBoard();
    }

    private void sDown_Click(object sender, EventArgs e)
    {
        for (int i = 0; i < scrollMultiplier; i++)
        {
            Square edge = GameContainer.findSquareByCoords((size[0] - 1) * sf + 1,
(size[1] - 1) * sf + 1);
            updateSquares(-1, false, sender);
            if (edge.indexY == bounds[2])
            {
                bounds[2]--;
                for (int j = bounds[0]; j <= bounds[1]; j++)
                {
                    board.Add(new Square
                    {
                        X = origin[0] + sf * j,
                        Y = origin[1] - bounds[2] * sf,
                        indexX = (short)j,
                        indexY = (short)bounds[2]
                    });
                }
            }
        }
        drawBoard();
    }

    private void sRight_Click(object sender, EventArgs e)
    {
        for (int i = 0; i < scrollMultiplier; i++)
        {
            Square edge = GameContainer.findSquareByCoords((size[0] - 1) * sf + 1,
(size[1] - 1) * sf + 1);
            updateSquares(-1, true, sender);
            if (edge.indexX == bounds[1])
            {
                bounds[1]++;
                for (int j = bounds[2]; j <= bounds[3]; j++)
                {
                    board.Add(new Square
                    {
                        X = origin[0] + bounds[1] * sf,
                        Y = origin[1] - sf * j,
                        indexX = (short)bounds[1],
                        indexY = (short)j
                    });
                }
            }
        }
        drawBoard();
    }

    private void sLeft_Click(object sender, EventArgs e)
    {
        for (int i = 0; i < scrollMultiplier; i++)
        {
            Square edge = GameContainer.findSquareByCoords(0, 0);
            updateSquares(1, true, sender);
            if (edge.indexX == bounds[0])
```

```
                {
                    bounds[0]--;
                    for (int j = bounds[2]; j <= bounds[3]; j++)
                    {
                        board.Add(new Square
                        {
                            X = origin[0] + bounds[0] * sf,
                            Y = origin[1] - sf * j,
                            indexX = (short)bounds[0],
                            indexY = (short)j
                        });
                    }
                }
            }
            drawBoard();
        }
        #endregion
    }
}
```

Classes.cs

```
using System.Collections.Generic;
using System.Windows.Forms;
using System.Drawing;
using System.Linq;
using System.Text.RegularExpressions;
using System.Threading;
using System.Diagnostics;
using System;
using System.Threading.Tasks;
using System.Timers;
using System.ComponentModel;

namespace InfiniteChess
{
    public partial class Chess : Form
    {
        public class GameContainer : Panel
        {
            public Chess c;

            public void handleTurn(Piece p, Square s) {
                if (!state.HasFlag(GameState.MOVE)) {
                    if (p != null && state.HasFlag(GameState.COLOUR) !=
p.colour.HasFlag(PieceColour.WHITE)) {
                        pieceMoving = p;
                        drawMoves(p);
                        state ^= GameState.MOVE;
                    }
                }
                else {
                    //colour of the other player
                    var colour = state.HasFlag(GameState.COLOUR) ? PieceColour.WHITE :
PieceColour.BLACK;
                    if (pieceMovingMoves.Contains(s)) {
                        c.history.addMove(pieceMoving, s);
                        lastMove = null;
                        bool cm = evaluateCheckMate(colour);
                        if (evaluateCheck(colour)) {
                            if (cm) {
                                state ^= (GameState.WIN | GameState.COLOUR);
                                c.history.addCheck(1);
                            }
```

```
                            else c.history.addCheck(0);
                            state ^= GameState.CHECK;
                        }
                        else if (cm) {
                            state ^= (GameState.STALE | GameState.COLOUR);
                            c.history.addCheck(2);
                        }
                        state ^= (GameState.MOVE | GameState.COLOUR);
                    }
                    else state ^= GameState.MOVE;
                    pieceMoving = null;
                    pieceMovingMoves = Square.emptyList();
                    c.drawBoard();
                    if (opponentAI && state.HasFlag((GameState)1))
                        c.AIThread.RunWorkerAsync();
                }
                c.stateLabel.Text = $"{parseState(state)}";
            }

            #region AI
            public AIMove handleAITurn(BackgroundWorker bw) {
                List<Piece> aipieces = pieces.FindAll(p => p.colour == PieceColour.BLACK);
                List<AIMove> moves = new List<AIMove>();
                foreach (Piece p in aipieces) {
                    List<Square> pieceMoves = p.calculateMovement(false);
                    Parallel.ForEach(pieceMoves, s => {
                        moves.Add(new AIMove(p, s));
                    });
                }
                int best = 9999999;
                List<AIMove> bestMoves = new List<AIMove>();
                foreach (AIMove m in moves) {
                    int current = 0;
                    Square original = m.p.square;
                    m.p.move(m.s, out Piece q);
                    Parallel.ForEach(pieces, y => {
                        int i = y.baseValue + y.addedValue;
                        Interlocked.Add(ref current, i);
                        });
                    m.p.move(original, out Piece _q);
                    if (q != null) { pieces.Add(q); }
                    if (current < best) {
                        best = current;
                        bestMoves.Clear();
                        bestMoves.Add(m);
                    }
                    if (current == best) {
                        bestMoves.Add(m);
                    }
                }
                Debug.WriteLine(best);
                if (new Random().NextDouble() > (0.25*(AIDIfficulty/100) + 0.82)) bestMoves
= moves;
                return bestMoves[(new Random()).Next(bestMoves.Count - 1)];
            }

            public void AIThread_DoWork(object sender, DoWorkEventArgs e)
            {
                state ^= GameState.MOVE;
                BackgroundWorker bw = sender as BackgroundWorker;
                e.Result = handleAITurn(bw);
            }
            public void AIThread_WorkCompleted(object sender, RunWorkerCompletedEventArgs
e)
            {
```

```
                var colour = state.HasFlag(GameState.COLOUR) ? PieceColour.WHITE :
PieceColour.BLACK;
                AIMove result = e.Result as AIMove;
                c.history.addMove(result.p, result.s);
                lastMove = null;
                bool cm = evaluateCheckMate(colour);
                if (evaluateCheck(colour)) {
                    if (cm) {
                        state ^= (GameState.WIN | GameState.COLOUR);
                        c.history.addCheck(1);
                    }
                    else c.history.addCheck(0);
                    state ^= GameState.CHECK;
                }
                else if (cm) {
                    state ^= (GameState.STALE | GameState.COLOUR);
                    c.history.addCheck(2);
                }
                state ^= (GameState.MOVE | GameState.COLOUR);
                c.drawBoard();
                c.stateLabel.Text = $"{parseState(state)}";
            }
            #endregion
            #region check
            public bool evaluateCheck(PieceColour c) {
                if (state.HasFlag(GameState.CHECK)) { state ^= GameState.CHECK; }
                Square king = pieces.Find(p => p.type == PieceType.KING && p.colour ==
c).square;
                for (int i = 0; i < pieces.Count(); i++) {
                    Piece p = pieces[i];
                    if (p.colour == c) continue;
                    short[] ps = new short[] { p.square.indexX, p.square.indexY };
                    short[] ks = new short[] { king.indexX, king.indexY };
                    switch (p.type) {
                        case (PieceType.ROOK): {
                                if (ps[0] != ks[0] & ps[1] != ks[1]) continue;
                                break;
                            }
                        case (PieceType.BISHOP): {
                                if (ps[0] - ps[1] != ks[0] - ks[1]) continue;
                                break;
                            }
                        case (PieceType.QUEEN): {
                                if (ps[0] != ks[0] & ps[1] != ks[1] & ps[0] - ks[0] !=
ps[1] - ks[1])
                                    continue;
                                break;
                            }
                        case (PieceType.CHANCELLOR): {
                                if (ps[0] != ks[0] & ps[1] != ks[1] &
                                    (Math.Abs(ps[0] - ks[0]) > 3 |
                                    Math.Abs(ps[1] - ks[1]) > 3)) continue;
                                break;
                            }
                        case (PieceType.HAWK): {
                                if (Math.Abs(ps[0] - ks[0]) > 3 |
                                    Math.Abs(ps[1] - ks[1]) > 3) continue;
                                break;
                            }
                        case (PieceType.PAWN): {
                                if (Math.Abs(ps[0] - ks[0]) > 2 |
                                    Math.Abs(ps[1] - ks[1]) > 2) continue;
                                break;
                            }
                        case (PieceType.MANN): {
```

```
                                if (Math.Abs(ps[0] - ks[0]) > 1 |
                                    Math.Abs(ps[1] - ks[1]) > 1) continue;
                                break;
                            }
                        case (PieceType.KNIGHT): {
                                if (Math.Abs(ps[0] - ks[0]) > 2 |
                                    Math.Abs(ps[1] - ks[1]) > 2) continue;
                                break;
                            }
                        case (PieceType.KING): {
                                if (Math.Abs(ps[0] - ks[0]) > 1 |
                                    Math.Abs(ps[1] - ks[1]) > 1) continue;
                                break;
                            }
                    }
                    if (p.calculateMovement(true).Contains(king)) return true;
                }
                return false;
            }

            public bool evaluateCheckMate(PieceColour c)
            {
                Piece king = pieces.Find(p => p.type == PieceType.KING && p.colour == c);
                if (king.calculateMovement(false).Count() != 0) return false;
                List<Piece> playerPieces = pieces.FindAll(p => p.colour == c);
                for (int i = 0; i < playerPieces.Count(); i++) {
                    if (playerPieces[i].calculateMovement(false).Count() != 0) return
false;
                }
                return true;
            }
            #endregion
            #region mouse stuff
            protected override void OnMouseClick(MouseEventArgs e)
            {
                Square cursorSquare = findSquareByCoords(e.X, e.Y);
                Piece found = pieces.Find(p => p.square == cursorSquare);
                Focus();
                if (e.Button == MouseButtons.Left) {
                    if (opponentAI & state.HasFlag((GameState)3)) return;
                    handleTurn(found, cursorSquare);
                }
                if (e.Button == MouseButtons.Right) {
                    if (found == null) return;
                    c.pieceContextMenu.Show(Cursor.Position);
                    c.pieceContextMenu.Text = prefixFromType(found.type);
                }
            }

            protected override void OnMouseMove(MouseEventArgs e)
            {
                c = getForm<Chess>();
                Square cursorSquare = findSquareByCoords(e.X, e.Y);
                if (cursorSquare == null) return;
                string s =
                    $"Cursor is over ({cursorSquare?.indexX.ToString()},
{cursorSquare?.indexY.ToString()})";
                Piece p = pieces.Find(q => q.square == cursorSquare) ?? null;
                if (p != null) {
                    s +=
                        $"\ncontaining {p.colour.ToString().ToLower()}
{p.type.ToString().ToLower()}";
                }
                c.cursorLabel.Text = s;
```

```
                //c.debug2.Text = bounds[]
            }
            #endregion
            #region util
            public void drawMoves(Piece p)
            {
                if (p == null) return;
                Graphics g = CreateGraphics();
                foreach (Square s in p.calculateMovement(false))
                {
                    pieceMovingMoves.Add(s);
                    if (!movementIndicators) continue;
                    int param = s.indexX + s.indexY;
                    //Color c = param % 2 == 0 ? Color.FromArgb(206,17,22) :
Color.FromArgb(255,34,44);
                    Color c = Color.FromArgb(206, 17, 22);
                    for (int j = 1; j < 18; j++) {
                        g.DrawRectangle(new Pen(Color.FromArgb(180 - (4*j), c)), s.X + j +
1, s.Y + j + 1, sf - 3 - (2*j), sf - 3 - (2*j));
                    }
                }
                g.Dispose();
            }
            public static TForm getForm<TForm>() where TForm : Form
            {
                return (TForm)Application.OpenForms[0];
            }
            public static Square findSquareByCoords(int x, int y)
            {
                var result = from s in board where x >= s.X && x < s.X + sf && y >= s.Y &&
y < s.Y + sf select s;
                return result.Count() > 0 ? result.ToArray()[0] : null;
            }

            public static Square findSquareByIndex(int indexX, int indexY)
            {
                var result = from s in board where indexX == s.indexX && indexY == s.indexY
select s;
                return result.Count() > 0 ? result.ToArray()[0] : null;
            }
            #endregion
            #region debug
            protected override void OnKeyPress(KeyPressEventArgs e) //debug function
            {
                Point a = Parent.PointToClient(new Point(Cursor.Position.X,
Cursor.Position.Y));
                Square cursorSquare = findSquareByCoords(a.X - Location.X, a.Y -
Location.Y);
                Piece target = null;
                foreach (Piece p in pieces) { if (p.square == cursorSquare) { target =
p; } }

                if (cursorSquare != null) {
                    if (target != null) {
                        if (e.KeyChar == 'e') pieces.Remove(target);
                        if (e.KeyChar == 'q') target.altColour();
                    }
                    else{
                        switch (e.KeyChar) {
                            case '#': {
                                    pieces.Add(new Piece(PieceType.NONE, cursorSquare,
PieceColour.WHITE));
                                    break;
                                }
                            case 'w': {
```

```
                                    pieces.Add(new Piece(PieceType.PAWN, cursorSquare,
PieceColour.WHITE));
                                    break;
                                }
                            case 'a': {
                                    pieces.Add(new Piece(PieceType.BISHOP, cursorSquare,
PieceColour.WHITE));
                                    break;
                                }
                            case 's': {
                                    pieces.Add(new Piece(PieceType.KNIGHT, cursorSquare,
PieceColour.WHITE));
                                    break;
                                }
                            case 'd': {
                                    pieces.Add(new Piece(PieceType.MANN, cursorSquare,
PieceColour.WHITE));
                                    break;
                                }
                            case 'z': {
                                    pieces.Add(new Piece(PieceType.HAWK, cursorSquare,
PieceColour.WHITE));
                                    break;
                                }
                            case 'x': {
                                    pieces.Add(new Piece(PieceType.ROOK, cursorSquare,
PieceColour.WHITE));
                                    break;
                                }
                            case 'c': {
                                    pieces.Add(new Piece(PieceType.CHANCELLOR,
cursorSquare, PieceColour.WHITE));
                                    break;
                                }
                            case 'r': {
                                    pieces.Add(new Piece(PieceType.QUEEN, cursorSquare,
PieceColour.WHITE));
                                    break;
                                }
                            case 'f': {
                                    pieces.Add(new Piece(PieceType.KING, cursorSquare,
PieceColour.WHITE));
                                    break;
                                }
                        }

                    }
                    c.drawBoard();
                }
            }
            #endregion
        }
        #region history
        public class MoveHistory : TextBox
        {
            public List<string> moves { get; private set; } = new List<string>();

            public void addMove(Piece p, Square s) {
                string[] data = p.ToString().Split(',');
                string moveText = $"{prefixFromType(p.type)}({data[2]},{data[3]})";
                p.move(s, out Piece pOut);
                if (pOut != null) {
                    data = pOut.ToString().Split(',');
                    moveText += $"x{prefixFromType(pOut.type)}({data[2]},{data[3]})";
                }
```

```
                else moveText += $"-({s.indexX},{s.indexY})";
                if (p.type == PieceType.PAWN && p.PawnData == true) {
                    p.PawnData = false;
                    moveText += "\x0091";
                }
                if (p.type == PieceType.PAWN) {
                    if (p.square.indexY == 11 && p.colour == PieceColour.WHITE
                        || p.square.indexY == 4 && p.colour == PieceColour.BLACK) {
                        if (opponentAI & state.HasFlag((GameState)1)) {
                            p.changeType(PieceType.QUEEN);
                            moveText += "Q";
                        }
                        else {
                            Promote pForm = new Promote();
                            pForm.ShowDialog();
                            p.changeType(pForm.choice);
                            moveText += pForm.choicePrefix;
                            pForm.Dispose();
                        }
                    }
                }
                moves.Add(moveText);
                updateMoves();
            }

            public void undoMove(int num) {
                for (int i = 0; i < num; i++) {
                    if (moves.Count() == 0) break;
                    string lastMove = moves.Last();
                    state ^= GameState.COLOUR;
                    moves.Remove(lastMove);
                    MatchCollection matchSquares = Regex.Matches(lastMove,
"-?\\d+,-?\\d+");
                    MatchCollection matchPieces = Regex.Matches(lastMove, "[A-Z]");
                    Square to = GameContainer.findSquareByIndex(
                        int.Parse(matchSquares[1].Value.Split(',')[0]),
                        int.Parse(matchSquares[1].Value.Split(',')[1])
                        );
                    Square from = GameContainer.findSquareByIndex(
                        int.Parse(matchSquares[0].Value.Split(',')[0]),
                        int.Parse(matchSquares[0].Value.Split(',')[1])
                        );
                    Piece p = pieces.Find(q => q.square == to);
                    try {
                        p.move(from, out Piece r);
                    }
                    catch { Debug.WriteLine("p was null"); break; }
                    if (matchPieces.Count >= 2) {
                        if (lastMove.Contains("x")) {
                            PieceType type = typeFromPrefix(matchPieces[1].Value);
                            PieceColour colour = moves.Count() % 2 == 0 ?
PieceColour.BLACK : PieceColour.WHITE;
                            pieces.Add(new Piece(type, to, colour));
                        }
                        if (Regex.IsMatch(lastMove.Substring(lastMove.Length - 2), "[A-
Z]")) {
                            p.changeType(PieceType.PAWN);
                            p.PawnData = false;
                        }
                    }
                    if (lastMove.Contains("\x0091")) p.PawnData = true;
                    if (lastMove.Contains('+')) state ^= (GameState)4;
                    if (lastMove.Contains('#')) state ^= (GameState)13;
                    if (lastMove.Contains('~')) state ^= (GameState)17;
                    if (state.HasFlag((GameState)2)) { state ^= (GameState)2; }
```

```
                    updateValues();
                    pieceMoving = null;
                    pieceMovingMoves = Square.emptyList();
                }
                updateMoves();
            }

            public void updateMoves() {
                List<string> result = new List<string>();
                for (int i = 0; i < moves.Count(); i += 2) {
                    int lineNo = (i + 1) / 2;
                    string line = $"{lineNo + 1}. {moves[i]}".PadRight(36);
                    if (moves.Count() != i + 1) line += $"{moves[i + 1]}";
                    result.Add(line);
                }
                Lines = result.ToArray();
                SelectionStart = TextLength;
                ScrollToCaret();
            }

            public void addCheck(int state) {
                if (state < 0 || state > 2) return;
                string[] symbols = { "+", "#", "~" };
                moves[moves.Count() - 1] += symbols[state];
                updateMoves();
            }

            public void setMoves(List<string> m) {
                moves = m;
                updateMoves();
            }

            public List<Square> getLastMoveSquares() {
                if (moves.Count == 0) return Square.emptyList();
                MatchCollection matchSquares = Regex.Matches(moves.Last(),
"-?\\d+,-?\\d+");
                Square to = GameContainer.findSquareByIndex(
                    int.Parse(matchSquares[1].Value.Split(',')[0]),
                    int.Parse(matchSquares[1].Value.Split(',')[1])
                    );
                Square from = GameContainer.findSquareByIndex(
                    int.Parse(matchSquares[0].Value.Split(',')[0]),
                    int.Parse(matchSquares[0].Value.Split(',')[1])
                    );
                return to + from;
            }
        }
    }
    #endregion
    #region square
    public class Square
    {
        public int X { get; set; }
        public int Y { get; set; } //actual coordinates
        public short indexX { get; set; }
        public short indexY { get; set; } //square reference
        public static List<Square> emptyList() => new List<Square> { };
        public override string ToString() =>
$"{indexX.ToString()},{indexY.ToString()},{X.ToString()},{Y.ToString()}";
        public static List<Square> operator +(Square s1, Square s2) => new List<Square>
{ s1, s2 };
    }
    #endregion
    #region AIMove
    public class AIMove
```

```
    {
        public Square s;
        public Piece p;
        public AIMove(Piece piece, Square square) {
            p = piece; s = square;
        }
        public override string ToString() => $"{p.ToString()} -> ({s.indexX}, {s.indexY})";
    }
    #endregion
}
```

Pieces.cs

```
using System;
using System.Collections.Generic;
using System.Drawing;
using System.IO;
using System.Diagnostics;
using System.Windows.Forms;
using System.Threading.Tasks;
using System.Threading;

namespace InfiniteChess
{
    public enum PieceType { PAWN, KNIGHT, ROOK, BISHOP, QUEEN, KING, MANN, HAWK,
CHANCELLOR, NONE };
    public enum PieceColour { BLACK, WHITE }; //WHITE moves up the board, BLACK down

    public class Piece
    {
        public PieceType type { get; private set; }
        public Square square { get; private set; }
        public Bitmap icon { get; private set; }
        public PieceColour colour { get; private set; }
        public bool PawnData { get; set; } = false;
        public int baseValue { get; set; }
        public int addedValue { get; set; }

        public Piece(PieceType t, Square s, PieceColour c) {
            type = t; colour = c; square = s;
            icon = new Bitmap($"res/image/pieces/icon/{c.ToString()}/{t.ToString()}.png");
            if (t == PieceType.PAWN) { PawnData = true; }
            int sign = colour == PieceColour.WHITE ? 1 : -1;
            switch (type) {
                case PieceType.PAWN: { baseValue = 1000 * sign; break; }
                case PieceType.BISHOP: { baseValue = 7000 * sign; break; }
                case PieceType.ROOK: { baseValue = 15000 * sign; break; }
                case PieceType.KNIGHT: { baseValue = 4000 * sign; break; }
                case PieceType.MANN: { baseValue = 4000 * sign; break; }
                case PieceType.HAWK: { baseValue = 12000 * sign; break; }
                case PieceType.CHANCELLOR: { baseValue = 18000 * sign; break; }
                case PieceType.QUEEN: { baseValue = 25000 * sign; break; }
                case PieceType.KING: { baseValue = 200000 * sign; break; }
                case PieceType.NONE: { baseValue = 0; break; }
            }
        }
        public Piece(PieceType t, Square s, PieceColour c, bool pd, int av) {
            type = t; colour = c; square = s; PawnData = pd; addedValue = av;
            icon = new Bitmap($"res/image/pieces/icon/{c.ToString()}/{t.ToString()}.png");
            int sign = colour == PieceColour.WHITE ? 1 : -1;
            switch (type) {
                case PieceType.PAWN: { baseValue = 1000 * sign; break; }
                case PieceType.BISHOP: { baseValue = 7000 * sign; break; }
```

```
                case PieceType.ROOK: { baseValue = 15000 * sign; break; }
                case PieceType.KNIGHT: { baseValue = 4000 * sign; break; }
                case PieceType.MANN: { baseValue = 4000 * sign; break; }
                case PieceType.HAWK: { baseValue = 12000 * sign; break; }
                case PieceType.CHANCELLOR: { baseValue = 18000 * sign; break; }
                case PieceType.QUEEN: { baseValue = 25000 * sign; break; }
                case PieceType.KING: { baseValue = 200000 * sign; break; }
                case PieceType.NONE: { baseValue = 0; break; }
            }
        }
        #region movement
        public void move(Square s, out Piece pOut) {
            Piece p = Chess.pieces.Find(q => q.square == s);
            pOut = p;
            if (p != null) {
                Chess.pieces.Remove(p);
                Chess.lastMove = p;
            }
            square = s;
            Chess.updateValues();
        }

        public List<Square> calculateInitMovement(bool includeKings) {
            List<Square> moves = Square.emptyList();
            switch (type) {
                case (PieceType.PAWN): {
                        int direction = colour == PieceColour.WHITE ? square.indexY + 1 :
square.indexY - 1;
                        for (int i = -1; i <= 1; i++) {
                            Square attempt =
Chess.GameContainer.findSquareByIndex(square.indexX + i, direction);
                            if (Chess.checkSquareForPiece(attempt, includeKings, colour) ==
Math.Abs(i)) moves.Add(attempt);
                        }
                        if (PawnData && moves.Count != 0) {
                            int direction2 = colour == PieceColour.WHITE ? square.indexY +
2 : square.indexY - 2;
                            Square attempt =
Chess.GameContainer.findSquareByIndex(square.indexX, direction2);
                            if (Chess.checkSquareForPiece(attempt, includeKings, colour) ==
0)
                                moves.Add(attempt);
                        }
                        return moves;
                    }
                case (PieceType.MANN): { goto case PieceType.KING; }
                case (PieceType.KNIGHT): { goto case PieceType.KING; }
                case (PieceType.HAWK): { goto case PieceType.KING; }
                case (PieceType.KING): {
                        string[] attempts =
File.ReadAllLines($"res/movement/{type.ToString()}.txt");
                        foreach (string att in attempts) {
                            Square s = Chess.GameContainer.findSquareByIndex(
                                square.indexX + int.Parse(att.Split(',')[0]),
                                square.indexY + int.Parse(att.Split(',')[1]));
                            if (Chess.checkSquareForPiece(s, includeKings, colour) != 2 &&
s != null) moves.Add(s);
                        }
                        return moves;
                    }
                case (PieceType.ROOK): { goto case PieceType.BISHOP; }
                case (PieceType.BISHOP): {
                    int[] tracker = { 0, 0, 0, 0 };
                    int[][] direction = type == PieceType.BISHOP ?
```

```
                        new int[][] { new int[]{-1,-1}, new int[]{-1,1}, new int[]{1,-1},
new int[]{1,1} } :
                        new int[][] { new int[]{-1,0}, new int[]{1,0}, new int[]{0,-1}, new
int[]{0,1} };
                    int max = Chess.findLargest(new int[] {
                        square.indexX-Chess.bounds[0], square.indexY-Chess.bounds[2],
                        Chess.bounds[1]-square.indexX, Chess.bounds[3]-square.indexY} );
                    for (int i = 1; i <= max; i++) {
                        for (int j = 0; j < 4; j++) {
                            if (tracker[j] != 2) {
                                Square attempt = Chess.GameContainer.findSquareByIndex(
                                    square.indexX - i*direction[j][0], square.indexY -
i*direction[j][1]) ?? square;
                                tracker[j] = Chess.checkSquareForPiece(attempt,
includeKings, colour);
                                if (tracker[j] != 2) {
                                    moves.Add(attempt);
                                    if (tracker[j] == 1) tracker[j] = 2;
                                }
                            }
                        }
                    }
                    return moves;
                }
                case PieceType.QUEEN: {
                        moves.AddRange(new Piece(
                            PieceType.BISHOP, square,
colour).calculateInitMovement(includeKings));
                        moves.AddRange(new Piece(
                            PieceType.ROOK, square,
colour).calculateInitMovement(includeKings));
                        return moves;
                    }
                case PieceType.CHANCELLOR: { //KNIGHT + ROOK
                        moves.AddRange(new Piece(
                            PieceType.KNIGHT, square,
colour).calculateInitMovement(includeKings));
                        moves.AddRange(new Piece(
                            PieceType.ROOK, square,
colour).calculateInitMovement(includeKings));
                        return moves;
                    }
                default:
                    return moves;
            }
        }

        public List<Square> calculateMovement(bool includeKings) {
            List<Square> moves = calculateInitMovement(includeKings);
            List<Square> newMoves = new List<Square>();
            Square original = square;

            foreach (Square s in moves) {
                newMoves.Add(s);
                move(s, out Piece q);
                Square king = new Square();
                king = Chess.pieces.Find(p => p.type == PieceType.KING && p.colour ==
colour).square;
                foreach (Piece y in Chess.pieces) {
                    if (y.colour == colour) continue;
                    if (y.calculateInitMovement(true).Contains(king)) { newMoves.Remove(s);
break; }
                }
                move(original, out q);
```

```
                if (Chess.lastMove != null) { Chess.pieces.Add(Chess.lastMove);
Chess.lastMove = null; }
            }
            return newMoves;
        }
        #endregion
        #region util
        public void altColour() {
            colour = colour == PieceColour.WHITE ? PieceColour.BLACK : PieceColour.WHITE;
            icon = new
Bitmap($"res/image/pieces/icon/{colour.ToString()}/{type.ToString()}.png");
        }
        public void changeType(PieceType t) {
            type = t;
            icon = new
Bitmap($"res/image/pieces/icon/{colour.ToString()}/{type.ToString()}.png");
            PawnData = true;
        }
        public override string ToString() => $"{type},{colour},{square.ToString()}";
        #endregion
        #region init
        public static List<Piece> IntializePieces()
        {
            List<Piece> pieces = new List<Piece>();
            string[] data = File.ReadAllLines("res/config/start.txt");
            foreach (string d in data) {
                string[] ds = d.Split(',');
                PieceColour colour = ds[3] == "W" ? PieceColour.WHITE : PieceColour.BLACK;
                pieces.Add(new Piece(Chess.typeFromPrefix(ds[0]),
Chess.GameContainer.findSquareByIndex(int.Parse(ds[1]), int.Parse(ds[2])), colour));
            }
            return pieces;
        }
        #endregion
    }
}
```

Menu.cs

```
using System;
using System.Windows.Forms;
using System.Collections.Generic;
using System.Linq;
using System.Text;
using System.Threading.Tasks;
using System.IO;
using System.ComponentModel;
using System.Drawing;

namespace InfiniteChess
{
    public partial class Chess : Form
    {
        #region game
        private void menu_game_new_Click(object sender, EventArgs e)
        {
            Init();
        }
        private void menu_game_save_Click(object sender, EventArgs e)
        {
            SaveFileDialog save = new SaveFileDialog();
            save.Filter = "Infinite Chess Game|*.icg";
            save.Title = "Save Game";
```

```
            save.InitialDirectory = "res/saves";
            save.ShowDialog();
            if (save.FileName != "")
            {
                StringBuilder sb = new StringBuilder();
                foreach (Piece p in pieces) {

sb.Append($"{prefixFromType(p.type)},{p.square.indexX},{p.square.indexY},{p.colour},{p.Pawn
Data},{p.addedValue};");
                }
                sb.Append("|");
                foreach (string s in history.moves) {
                    sb.Append($"{s};");
                }
                sb.Remove(sb.Length - 1, 1);

sb.Append($"|{bounds[0]};{bounds[1]};{bounds[2]};{bounds[3]};{(int)state}");
                using (StreamWriter sw = new StreamWriter(save.FileName))
                {
                    sw.WriteLine(sb);
                    sw.Close();
                }
            }
        }
        private void menu_game_load_Click(object sender, EventArgs e)
        {
            OpenFileDialog open = new OpenFileDialog();
            open.Filter = "Infinite Chess Game|*.icg";
            open.Title = "Open Game";
            open.InitialDirectory = "res/saves";
            open.ShowDialog();
            string data = "";
            if (open.FileName != "") {
                using (StreamReader sr = new StreamReader(open.FileName))
                {
                    data = sr.ReadToEnd();
                    sr.Close();
                }
            }
            if (data == "") return;
            string[] data_pieces = data.Split('|')[0].Split(';');
            string[] data_history = data.Split('|')[1].Split(';');
            string[] data_state = data.Split('|')[2].Split(';');

            List<Piece> piecesLoad = new List<Piece>();
            bounds = new int[4];
            board = new List<Square>();
            origin = new int[] { 0, sf * (size[1] - 1) };
            state = (GameState)int.Parse(data_state[4]);
            for (int i = 0; i < 4; i++) {
                bounds[i] = int.Parse(data_state[i]);
            }
            InitialiseBoard();
            InitialiseButtons(true);
            foreach (string s in data_pieces) {
                if (s == "") continue;
                string[] p = s.Split(',');
                PieceType t = typeFromPrefix(p[0]);
                Square sq = GameContainer.findSquareByIndex(int.Parse(p[1]),
int.Parse(p[2]));
                PieceColour c = p[3] == "WHITE" ? PieceColour.WHITE : PieceColour.BLACK;
                bool pd = bool.Parse(p[4]);
                int av = int.Parse(p[5]);
                piecesLoad.Add(new Piece(t, sq, c, pd, av));
            }
```

```
            InitialisePieces(piecesLoad);
            history.setMoves(data_history.ToList());
        }
        private void menu_game_undo_Click(object sender, EventArgs e)
        {
            undo1.PerformClick();
        }
        private void menu_game_undo2_Click(object sender, EventArgs e)
        {
            undo2.PerformClick();
        }
        private void menu_game_exit_Click(object sender, EventArgs e)
        {
            Application.Exit();
        }
        private void menu_game_forfeit_Click(object sender, EventArgs e)
        {
            if (history.moves.Count > 0) {
                state ^= ((GameState)9);
                history.addCheck(1);
                stateLabel.Text = $"{parseState(state)}";
            }
            else stateLabel.Text = "Cannot forfeit on first turn!";
        }
        #endregion
        #region window
        private void menu_window_ui_hist_Click(object sender, EventArgs e)
        {
            bool hidden = history.Visible;
            history.Visible = !hidden;
            menu_window_ui_hist.Checked = !hidden;
        }
        private void menu_window_ui_move_Click(object sender, EventArgs e)
        {
            bool enabled = movementIndicators;
            movementIndicators = !enabled;
            menu_window_ui_move.Checked = !enabled;
        }
        private void menu_window_res_720_Click(object sender, EventArgs e)
        {
            setResolution(false);
        }
        private void menu_window_res_1080_Click(object sender, EventArgs e)
        {
            setResolution(true);
        }
        private void setResolution(bool b) {
            is1080 = b;
            menu_window_res_720.Checked = !b;
            menu_window_res_1080.Checked = b;
            if (b) {
                SetDesktopLocation(Location.X, 60);
            }
            InitialiseStyle();
            drawBoard();
        }
        #endregion
        #region setting
        private void menu_setting_ai_Click(object sender, EventArgs e)
        {
            AIDiff d = new AIDiff();
            d.setSliderValue(AIDIfficulty);
            d.ShowDialog();
            AIDIfficulty = d.difficulty;
            d.Dispose();
```

```
        }
        private void menu_setting_opp_human_Click(object sender, EventArgs e)
        {
            setOpponent(false);
        }
        private void menu_setting_opp_ai_Click(object sender, EventArgs e)
        {
            setOpponent(true);
        }
        private void setOpponent(bool ai) {
            menu_setting_opp_human.Checked = !ai;
            menu_setting_opp_ai.Checked = ai;
            opponentAI = ai;
        }
        private void menu_setting_scroll_scroll_up_Click(object sender, EventArgs e)
        {
            sUp.PerformClick();
        }
        private void menu_setting_scroll_scroll_down_Click(object sender, EventArgs e)
        {
            sDown.PerformClick();
        }
        private void menu_setting_scroll_scroll_left_Click(object sender, EventArgs e)
        {
            sLeft.PerformClick();
        }
        private void menu_setting_scroll_scroll_right_Click(object sender, EventArgs e)
        {
            sRight.PerformClick();
        }
        private void menu_setting_scroll_mult_1_Click(object sender, EventArgs e)
        {
            setScrollMult(1);
        }
        private void menu_setting_scroll_mult_2_Click(object sender, EventArgs e)
        {
            setScrollMult(2);
        }
        private void menu_setting_scroll_mult_3_Click(object sender, EventArgs e)
        {
            setScrollMult(3);
        }
        private void menu_setting_scroll_mult_4_Click(object sender, EventArgs e)
        {
            setScrollMult(4);
        }
        private void setScrollMult(int s) {
            for (int i = 0; i < 4; i++) {
                ToolStripMenuItem t = menu_setting_scroll_mult.DropDownItems[i] as
ToolStripMenuItem;
                if (i == s-1) t.Checked = true;
                else t.Checked = false;
            }
            scrollMultiplier = s;
        }
        private void menu_setting_undo_Click(object sender, EventArgs e)
        {
            bool enabled = !undo1.Enabled;
            undo1.Enabled = enabled;
            undo1.Visible = enabled;
            undo2.Enabled = enabled;
            undo2.Visible = enabled;
            menu_game_undo.Enabled = enabled;
            menu_game_undo2.Enabled = enabled;
            menu_setting_undo.Checked = !enabled;
```

```
        }
        #endregion
        #region about
        private void menu_about_about_Click(object sender, EventArgs e)
        {
            About a = new About();
            a.ShowDialog();
        }
        #endregion
        #region context
        private void pieceContextMenu_Opening(object sender, CancelEventArgs e)
        {
        }
        private void pieceInfoContextItem_Click(object sender, EventArgs e)
        {
            string type = pieceContextMenu.Text;
            string text = File.ReadAllText($"res/help/text/{pieceContextMenu.Text}.txt");
            Bitmap image = new Bitmap($"res/help/image/{pieceContextMenu.Text}.png");
            PieceInfo p = new PieceInfo(typeFromPrefix(type).ToString(), text, image);
            p.ShowDialog();
        }
        #endregion
    }
}
```

PieceInfo.cs

```
using System;
using System.Collections.Generic;
using System.ComponentModel;
using System.Data;
using System.Drawing;
using System.Linq;
using System.Text;
using System.Threading.Tasks;
using System.Windows.Forms;

namespace InfiniteChess
{
    public partial class PieceInfo : Form
    {
        public PieceInfo(string ty, string te, Bitmap b)
        {
            InitializeComponent();
            InitialiseStyle();
            pieceInfoTitle.Text = ty;
            pieceInfoText.Text = te;
            pieceInfoImage.BackgroundImage = b;
            pieceInfoImage.Focus();
            pieceInfoText.Select(0, 0);
            pieceInfoClose.Focus();
        }

        public void InitialiseStyle()
        {
            Color highlight = Color.FromKnownColor(KnownColor.Control);
            BackColor = Color.FromKnownColor(KnownColor.Control);
            foreach (Control c in Controls)
            {
                if (c.GetType() == typeof(Button))
                {
                    Button b = c as Button;
                    b.FlatStyle = FlatStyle.Flat;
                    b.BackColor = highlight;
```

```
                    b.FlatAppearance.BorderColor = Color.Black;
                    b.FlatAppearance.BorderSize = 1;
                    b.FlatAppearance.MouseDownBackColor = Color.LightGray;
                    b.FlatAppearance.MouseOverBackColor = Color.FromArgb(224, 224, 224);
                    b.ForeColor = Color.Black;
                }
                c.Font = new Font("Perpetua", 12);
            }
            pieceInfoTitle.Font = new Font("Perpetua", 16, FontStyle.Bold);
        }

        private void pieceInfoClose_Click(object sender, EventArgs e)
        {
            Close();
        }
    }
}
```

About.cs

```
using System;
using System.Collections.Generic;
using System.ComponentModel;
using System.Drawing;
using System.Linq;
using System.Reflection;
using System.Threading.Tasks;
using System.Windows.Forms;

namespace InfiniteChess
{
    partial class About : Form
    {
        public About()
        {
            InitializeComponent();
            InitialiseStyle();
            this.Text = String.Format("About {0}", AssemblyTitle);
            this.labelProductName.Text = AssemblyProduct;
            this.labelVersion.Text = String.Format("Version {0}", AssemblyVersion);
            this.labelCopyright.Text = AssemblyCopyright;
            this.labelCompanyName.Text = AssemblyCompany;
            //this.textBoxDescription.Text = AssemblyDescription;
        }

        public void InitialiseStyle()
        {
            Color highlight = Color.FromKnownColor(KnownColor.Control);
            BackColor = Color.FromKnownColor(KnownColor.Control);
            foreach (Control c in Controls)
            {
                if (c.GetType() == typeof(Button))
                {
                    Button b = c as Button;
                    b.FlatStyle = FlatStyle.Flat;
                    b.BackColor = highlight;
                    b.FlatAppearance.BorderColor = Color.Black;
                    b.FlatAppearance.BorderSize = 1;
                    b.FlatAppearance.MouseDownBackColor = Color.LightGray;
                    b.FlatAppearance.MouseOverBackColor = Color.FromArgb(224, 224, 224);
                    b.ForeColor = Color.Black;
                }
                c.Font = new Font("Perpetua", 10, FontStyle.Bold);
            }
```

```
        }

        #region Assembly Attribute Accessors

        public string AssemblyTitle
        {
            get
            {
                object[] attributes =
Assembly.GetExecutingAssembly().GetCustomAttributes(typeof(AssemblyTitleAttribute), false);
                if (attributes.Length > 0)
                {
                    AssemblyTitleAttribute titleAttribute =
(AssemblyTitleAttribute)attributes[0];
                    if (titleAttribute.Title != "")
                    {
                        return titleAttribute.Title;
                    }
                }
                return
System.IO.Path.GetFileNameWithoutExtension(Assembly.GetExecutingAssembly().CodeBase);
            }
        }

        public string AssemblyVersion
        {
            get
            {
                return Assembly.GetExecutingAssembly().GetName().Version.ToString();
            }
        }

        public string AssemblyDescription
        {
            get
            {
                object[] attributes =
Assembly.GetExecutingAssembly().GetCustomAttributes(typeof(AssemblyDescriptionAttribute),
false);
                if (attributes.Length == 0)
                {
                    return "";
                }
                return ((AssemblyDescriptionAttribute)attributes[0]).Description;
            }
        }

        public string AssemblyProduct
        {
            get
            {
                object[] attributes =
Assembly.GetExecutingAssembly().GetCustomAttributes(typeof(AssemblyProductAttribute),
false);
                if (attributes.Length == 0)
                {
                    return "";
                }
                return ((AssemblyProductAttribute)attributes[0]).Product;
            }
        }

        public string AssemblyCopyright
        {
            get
```

```
            {
                object[] attributes =
Assembly.GetExecutingAssembly().GetCustomAttributes(typeof(AssemblyCopyrightAttribute),
false);
                if (attributes.Length == 0)
                {
                    return "";
                }
                return ((AssemblyCopyrightAttribute)attributes[0]).Copyright.Insert(12,
"Andrew Keown").Replace('7', '8');
            }
        }

        public string AssemblyCompany
        {
            get
            {
                object[] attributes =
Assembly.GetExecutingAssembly().GetCustomAttributes(typeof(AssemblyCompanyAttribute),
false);
                if (attributes.Length == 0)
                {
                    return "";
                }
                return ((AssemblyCompanyAttribute)attributes[0]).Company;
            }
        }
        #endregion
    }
}
```

AIDiff.cs

```
using System;
using System.Collections.Generic;
using System.ComponentModel;
using System.Data;
using System.Drawing;
using System.Linq;
using System.Text;
using System.Threading.Tasks;
using System.Windows.Forms;

namespace InfiniteChess
{
    public partial class AIDiff : Form
    {
        public int difficulty = 0;

        public AIDiff()
        {
            InitializeComponent();
            InitialiseStyle();
        }

        public void InitialiseStyle() {
            Color highlight = Color.FromKnownColor(KnownColor.Control);
            BackColor = Color.FromKnownColor(KnownColor.Control);
            foreach (Control c in Controls) {
                if (c.GetType() == typeof(Button)) {
                    Button b = c as Button;
                    b.FlatStyle = FlatStyle.Flat;
                    b.BackColor = highlight;
                    b.FlatAppearance.BorderColor = Color.Black;
```

```
                    b.FlatAppearance.BorderSize = 1;
                    b.FlatAppearance.MouseDownBackColor = Color.LightGray;
                    b.FlatAppearance.MouseOverBackColor = Color.FromArgb(224, 224, 224);
                    b.ForeColor = Color.Black;
                }
                c.Font = new Font("Perpetua", 9, FontStyle.Bold);
            }
        }

        public void setSliderValue(int d) {
            AIDiffSlider.Value = d;
        }

        private void AIDiffSlider_Scroll(object sender, EventArgs e) {
            difficulty = AIDiffSlider.Value;
        }
    }
}
```

Promote.cs

```
using System;
using System.Collections.Generic;
using System.ComponentModel;
using System.Data;
using System.Diagnostics;
using System.Drawing;
using System.Linq;
using System.Text;
using System.Threading.Tasks;
using System.Windows.Forms;

namespace InfiniteChess
{
    public partial class Promote : Form
    {
        public PieceType choice;
        public string choicePrefix;

        public Promote()
        {
            InitializeComponent();
            InitialiseStyle();
        }

        public void InitialiseStyle() {
            Color highlight = Color.FromKnownColor(KnownColor.Control);
            BackColor = Color.FromArgb(200, 200, 200);
            foreach (Control c in Controls) {
                if (c.GetType() == typeof(Button)) {
                    Button b = c as Button;
                    b.FlatStyle = FlatStyle.Flat;
                    b.BackColor = highlight;
                    b.FlatAppearance.BorderColor = Color.Black;
                    b.FlatAppearance.BorderSize = 1;
                    b.FlatAppearance.MouseDownBackColor = Color.LightGray;
                    b.FlatAppearance.MouseOverBackColor = Color.FromArgb(224, 224, 224);
                    b.ForeColor = Color.Black;
                }
                c.Font = new Font("Perpetua", 9, FontStyle.Bold);
            }
        }

        private void promoteClick(object sender, EventArgs e)
```

```
        {
            Button b = sender as Button;
            string data = b.Name.TrimStart('p');
            choicePrefix = data;
            choice = Chess.typeFromPrefix(data);
            Close();
        }
    }
}
```

Section 4: Evaluation

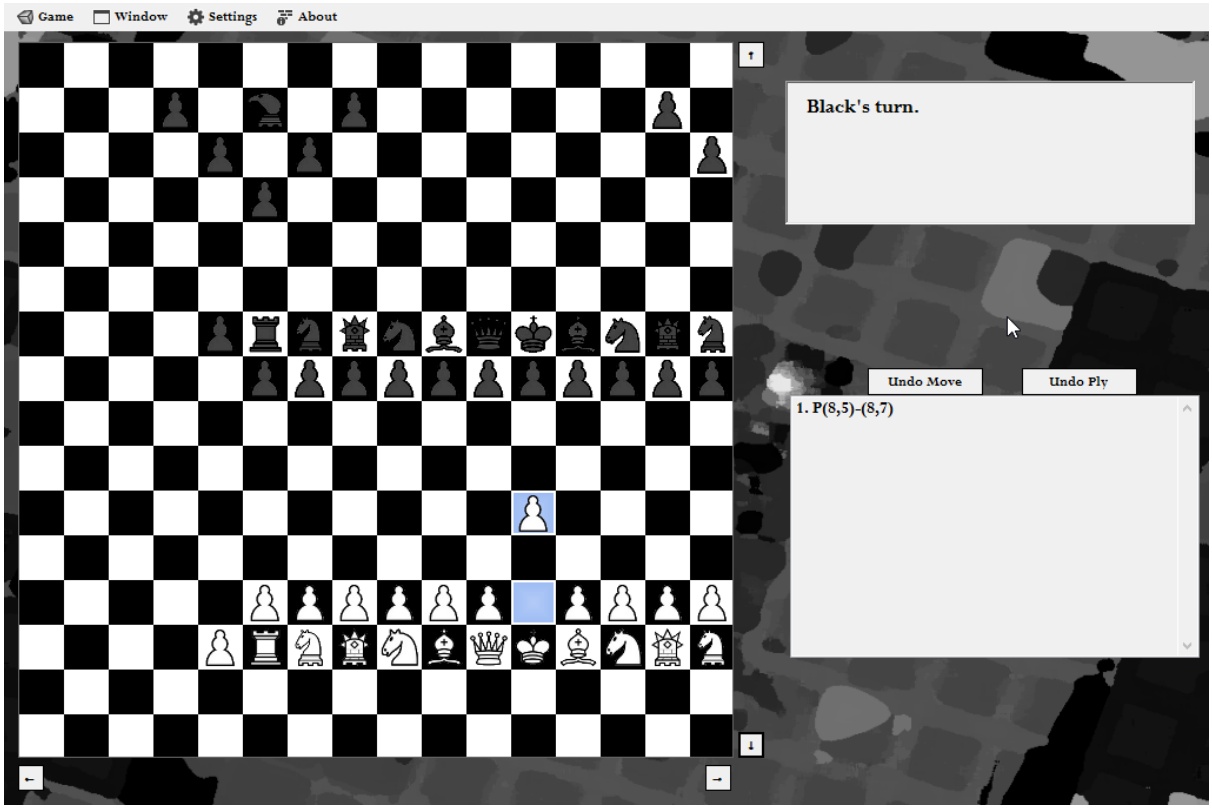
Post-Development Testing

I will now undertake some testing of the application as a whole since it is now complete. As before, I will use videos to show the results of these tests.

I will begin by testing the features listed in Essential Features, since these are the most important parts of the game.

Resolution Testing

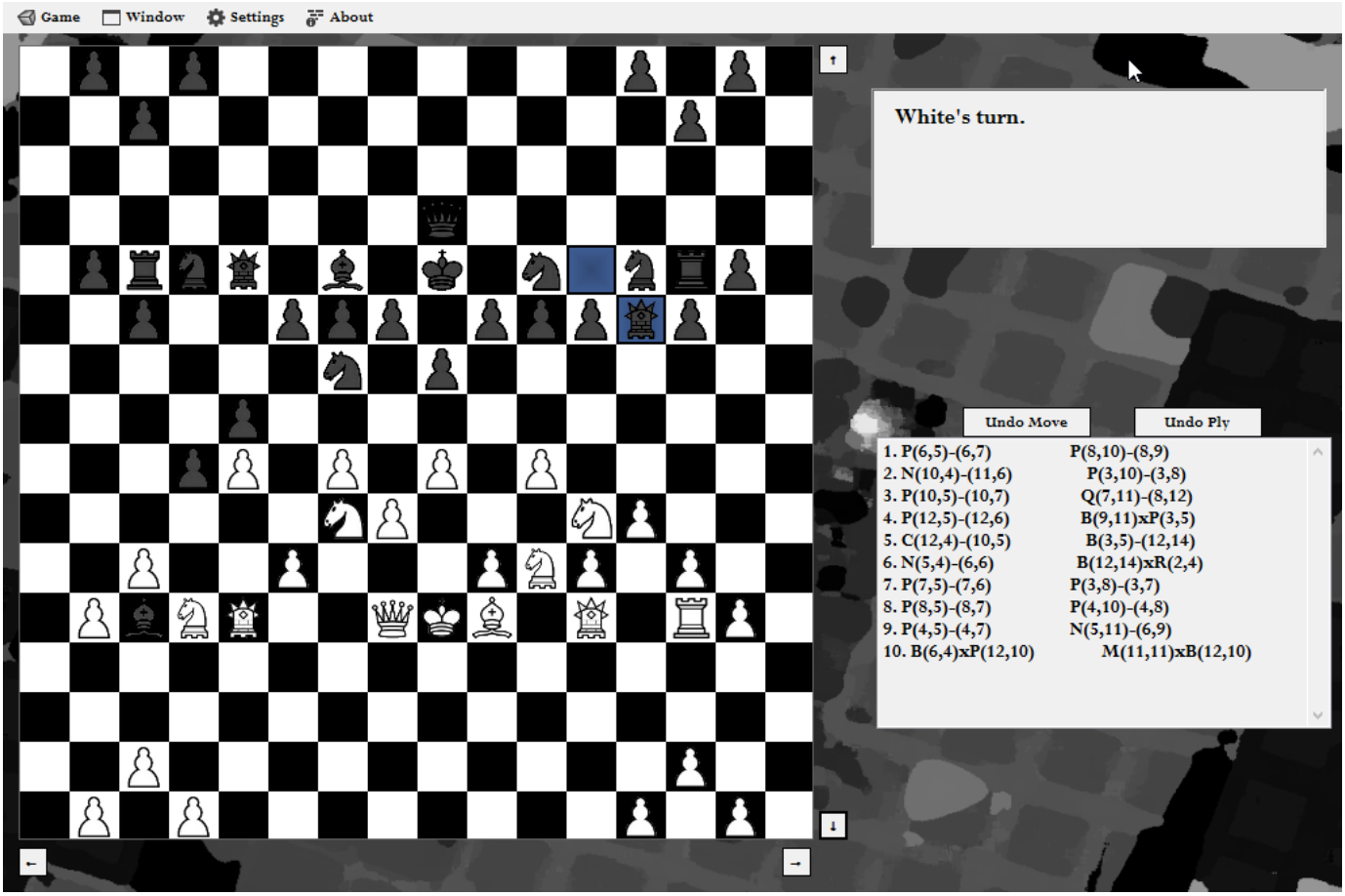
- I will start the game and use the menu button to change the resolution from 720p to 1080p. I will then start a new game, make a move, and then set the resolution back to 720p.
- The window should grow in size, along with the board and the move history. Each control should be in an appropriate place on the new larger window. Nothing should be drawn to the board when the game is resized. After new game is pressed, a game should begin. When the game is set back to 720p, the window and controls should appear as they did before. The board should still be drawn and the move I made should be visible.
- Below is the state after the test is complete.



- The resolution was correctly changed both times and the board was only drawn after the game had been started, as expected.

Opponent Testing

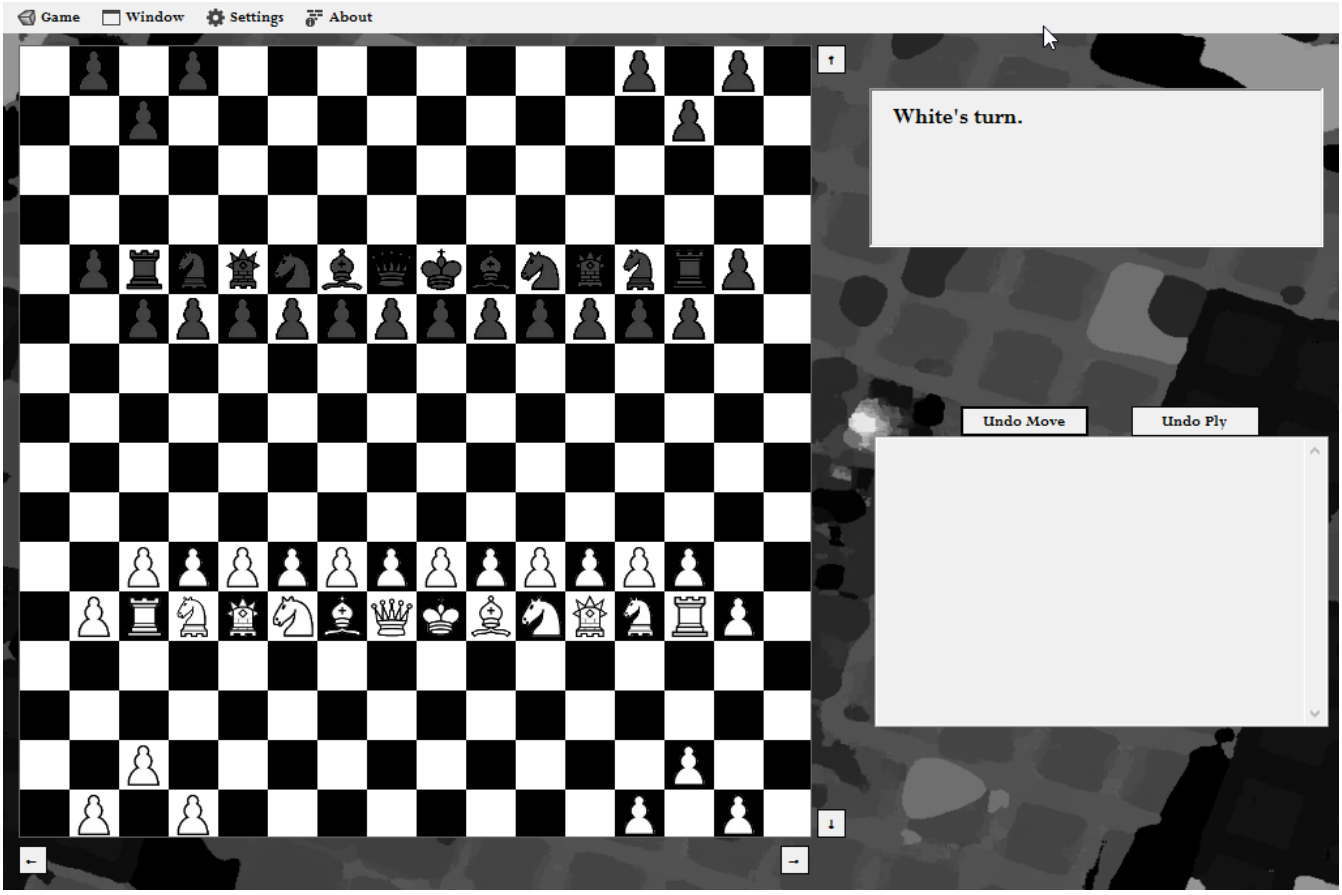
- I will start the game and make 2 moves for each player. I will then set the opponent to AI and make two more moves. The AI difficulty will then be changed from minimum to maximum and some more moves will be made.
- I should be able to make moves for both players initially, and then after setting the opponent to AI, I should not have any control of the pieces during black's turn. The AI should continue even after I change the difficulty from low to high.
- This is the state of the game after the test:



- The outcome was as expected. I made the first two moves for black, and after setting the AI opponent, it made all future moves for black, even after I changed the difficulty.

Rewinding Test

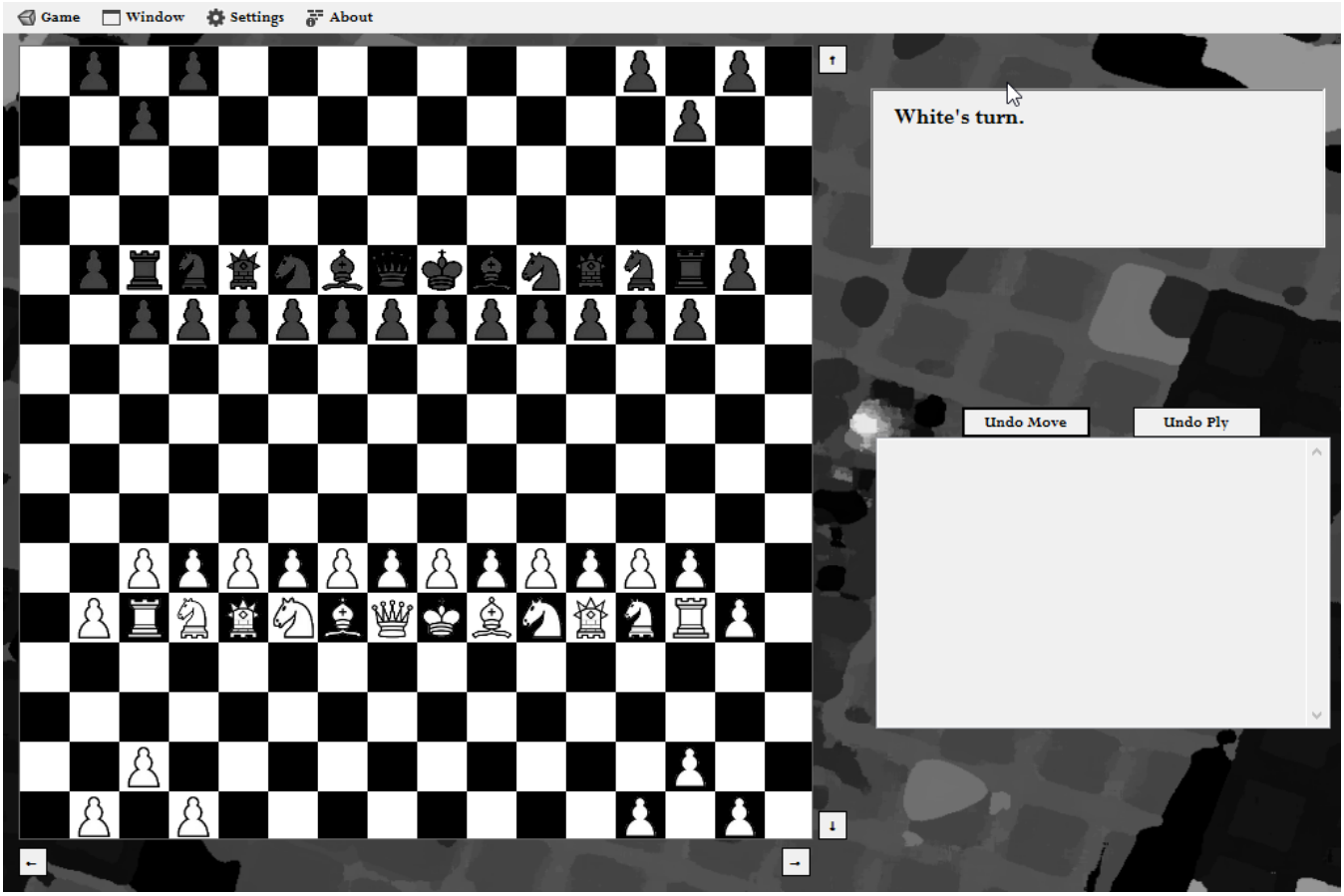
- I will activate the AI and make a series of moves. I will then undo some moves, disable the undo button, and make some more moves. I will then attempt to use the menu button to undo moves. I will then re-enable the undo button and undo the game back to the start.
- After each move is undone, the blue indicators for the last move made should update correctly. I should not be able to undo moves while the undo button is disabled. After the undo button is re-enabled and I undo every move, the game should appear identical to it is when a new game is started.



- The outcome was as expected. The game appears the same as it did when a new game was started. Moves were only able to be undone at the appropriate times, and the blue movement indicators were correctly updated.

History Testing

- I will start a new game and make some moves. I will then increase the resolution to 1080p and make additional moves. Then the move history will be hidden, the resolution set back to 720p, every move will be undone, and then the history will be re-enabled.
- The history should correctly record each move. The history should be unchanged except for size when the resolution changes. The history should also record moves made when it is hidden, including moves that get undone.
- Below is the state of the game after the test is complete:



- The history correctly recorded each move, even when it was hidden, the resolution was changed, and moves were undone.

Given the results of these final tests, and all the tests that have come before it, I can conclude that each feature of my program is comprehensively working as expected.

Usability and Robustness Testing

I need to evaluate the usability and robustness of my game. In order to do this, I will need other people to test and use the game.

An important aspect of the game is the user-friendliness. I added the menu bar to try and make it as simple to navigate the features of the game, so it will be vital to see what other people think of it. I have asked some of my classmates to test out the program and score various aspects out of 10:

How easy is it to use and play the game in general?	7	8	8	7	7	9	8	7.7
How easy is it to navigate the menu?	8	8	9	8	8	6	7	7.7
Are the graphics/UI features helpful/well designed?	6	7	6	6	8	7	6	6.6
How easy is it to save/load/create games?	8	8	9	8	8	7	8	8
How is the performance of the game?	6	6	5	7	6	7	7	6.3
How interesting/fun is the game to play?	6	7	7	6	8	9	7	7.1
How polished does the game feel?	6	5	7	8	7	6	6	6.4
								Average

These scores are generally quite high; in the 6 – 8 range. The three usability focused scores (1st, 2nd, 4th) all scored particularly highly, averaging 7.8. This indicates the time spent developing the menu bar was worth it.

The performance of the game was the lowest scoring section. It seems that while the performance of the game is reasonably good on my own PC, on lower spec systems the performance suffers a little. For example, the time taken for the AI to make a move on my PC will be at most 1-2 seconds. On another system, depending on the specific board configuration, it sometimes takes up to 5 seconds for a move to be made. This is simply due to the infinite nature of the game; there are many calculations that have to be made. While I could have spent more development time to try and increase the efficiency of the game further in these situations, I felt that the performance was reasonable and it would not be worth the extra time to improve it further.

To test robustness, I have been playing the game myself over a period of time, both against the AI and against players.

One problem I have noticed is that from the starting configuration, scrolling 16 squares down or right causes the game to crash. This does not happen when scrolling up or to the left. This is a difficult issue to notice during development or testing since in most games players will not scroll 16 squares in any direction.

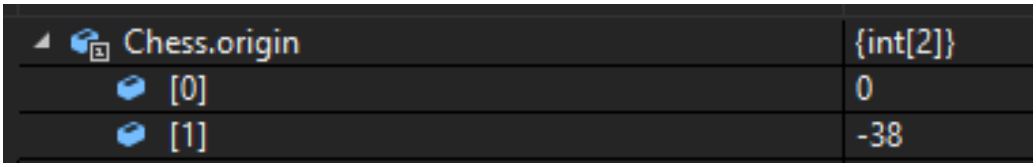
The crash causes because the game is unable to find the image specified in the following code when such scrolling happens:

```
int boardPolarity = (origin[0] / sf + origin[1] / sf) % 2;
g.DrawImage( new Bitmap(
        new Bitmap($"res/image/board/{boardPolarity.ToString()}board{size[0].ToString()}.png"),
        new Size(sf * size[0], sf * size[1])), 0, 0
    );
```

My assumption was that the modulo 2 function (% 2) would only return either 0 or 1, in which case there would be no problem. However, looking at the local variables when the crash occurs:

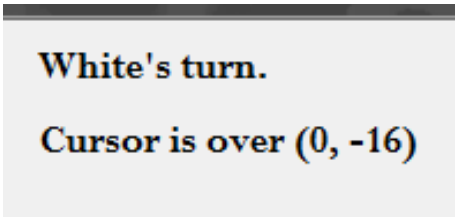
This value is set to -1. Clearly there is some behaviour that I did not expect.

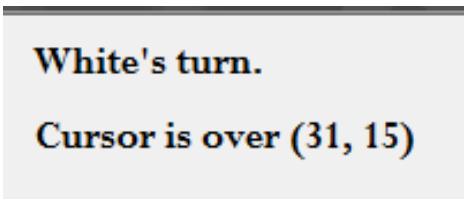
Looking at the values of origin when the crash occurs:



I can now see that the crash happens when one of the coordinates of the (0,0) becomes negative. The modulo of a negative number will return a negative value, so `boardPolarity` will be either 0 or -1 when the origin coordinates are below 0. This happens when the board is scrolled 16 squares to either the left or down.

To fix this, all I need to do is take the absolute value of the value returned by the modulo. This will cause it to return 1 instead of -1, and leave the other values unchanged. I am now able to scroll more than 16 squares right or down after implementing this fix:





Aside from this, the game appears to be a robust application. This concludes usability and robustness testing, with both being a success.

Requirement Evaluation

1. Generates squares on the fly
    - The game starts with a certain board size and grows it as necessary, adding rows or columns of squares depending on the scroll direction.
    - This is evident in the various board related tests I have done throughout development, and as part of final testing.
    - This requirement has been fully met.
2. Game will be saved on exit.
    - This feature was not implemented in the way originally planned.
    - Instead of saving automatically on exit, I have implemented manual saving and loading of games.
    - I decided to do this so that there are no unnecessary saves created, and to add the ability to load any saved game (not just the last one).
    - This is evident from the testing in saving and loading.
    - This requirement has been partially met, a similar feature was added instead.
3. Can resize to different resolutions
    - The user can use the menu item to select between two different resolutions; 720p and 1080p.
    - These two resolutions were the ones I decided on in my design section as a result of the survey I conducted on the matter.
    - This is evident from the resolution test in post development testing.
    - This requirement has been fully met.
4. Has move rewinding
    - Rewinding either moves or plies is an option in the game.
    - This can be done with the button above the move history, the menu item, or the keyboard shortcut.
    - Undoing correctly removes entries from the history, updates the game state and updates the last move indicators.
    - This is evident from the move history testing.
    - This requirement has been fully met.
5. Has human or AI opponent
    - The user can select between human and AI opponents using the menu item.
    - The opponent can be changed at any point during the game and enabling AI opponent disables making moves for the black turn.
    - This is evident from the opponent testing in post development testing.
    - This requirement has been fully met.

6. Has variable AI difficulty
    - The user can change set difficulty on a sliding scale using the menu item.
    - The difficulty can be changed at any time during a game.
    - This is evident from the opponent testing.
    - This requirement has been fully met.
7. Has a toolbar for navigation
    - There is a toolbar containing all the useful features for the game.
    - I decided that a toolbar would be the most convenient way to navigate the game, as outlined in my design section.
    - This is evident from the various tests in post development testing, as they all make use of the toolbar.
    - This requirement has been fully met.
8. Has a move history on screen
    - There is a history which keeps track of all moves that happen.
    - It works as expected in conjunction with the other features, such as undoing moves, AI opponent, and window resizing.
    - This is evident from the post development history testing.
    - This requirement has been fully met.
9. Has on-screen buttons to scroll the board
    - There are four buttons next to the board which scroll the board in a certain direction.
    - Scrolling can also be done with the menu item, and with a keyboard shortcut.
    - This is evident from the post development scrolling testing.
    - This requirement has been fully met.
10. Shows the user where they can move when they click on a piece
    - Clicking on a piece of your colour while it is your turn creates red highlighting on all the possible moves for that piece.
    - This is redrawn accurately if the board is scrolled while movement is being shown.
    - Highlighting is not shown for pieces that cannot be moved (no possible moves for a piece, opposite player's piece).
    - This is evident from the various tests, including those in post development, as all of them involve moving pieces.
    - This requirement has been fully met.

11. Shows the user which pieces were taken
    - The move history indicates when pieces have been taken.
    - The character 'x' indicates a capture.
    - This is not quite the implementation I originally intended, but I decided that displaying 70 pieces that have been captured would be unnecessary and unwieldy.
    - This requirement has been partially met.
12. Has keyboard keys to scroll the board
    - The user can press ctrl + an arrow key to scroll the board in a certain direction.
    - This shortcut is listed in the menu.
    - This feature has been tested in many of the previous tests, as they involve scrolling.
    - This requirement has been fully met.
13. The undo button can be disabled
    - The menu contains a button which disables the undo button.
    - It also disables the menu button for undoing, as well as the keyboard shortcut.
    - This is evident from the rewinding test.
    - This requirement has been fully met.
14. Tells the user if an attempted move is invalid.
    - The game displays a message if a piece they click has no available moves.
    - No message is displayed if a piece has moves but the user does not click on one of them. The game simply removes the highlighted moves from the board and does not change the turn to the next player.
    - I decided not to explicitly notify the user if the move they attempted is invalid since they will be able to clearly see if the move was successful
    - This requirement was not met.

I met all but three of the requirements; two were partially met or met in a different way than originally intended, and one was not met. The reasons for these criteria not being met were explained earlier. In each case, I feel that there was a valid justification. The evidence for each of the other requirements is contained in one of the previous testing sections (though most are in post-development testing), so overall I can conclude that I successfully met the software requirements that I outlined for the game.

Solution Maintenance

Further Development

Section 5: Bibliography

References

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Sources

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[2]https://cdn-images-1.medium.com/max/1600/1*UA5VlNs7s4gl80VknA099w.jpeg

[3]https://www.microsoft.com/en-us/download/details.aspx?id=35825

Videos

Video evidence mentioned in this document can be found in a separate folder called "Videos". Within this is a series of folders which are named after the section of the document they belong to.